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Cascade Impactor Data Reduction with SR-52 and TI-59 Programmable Calculators

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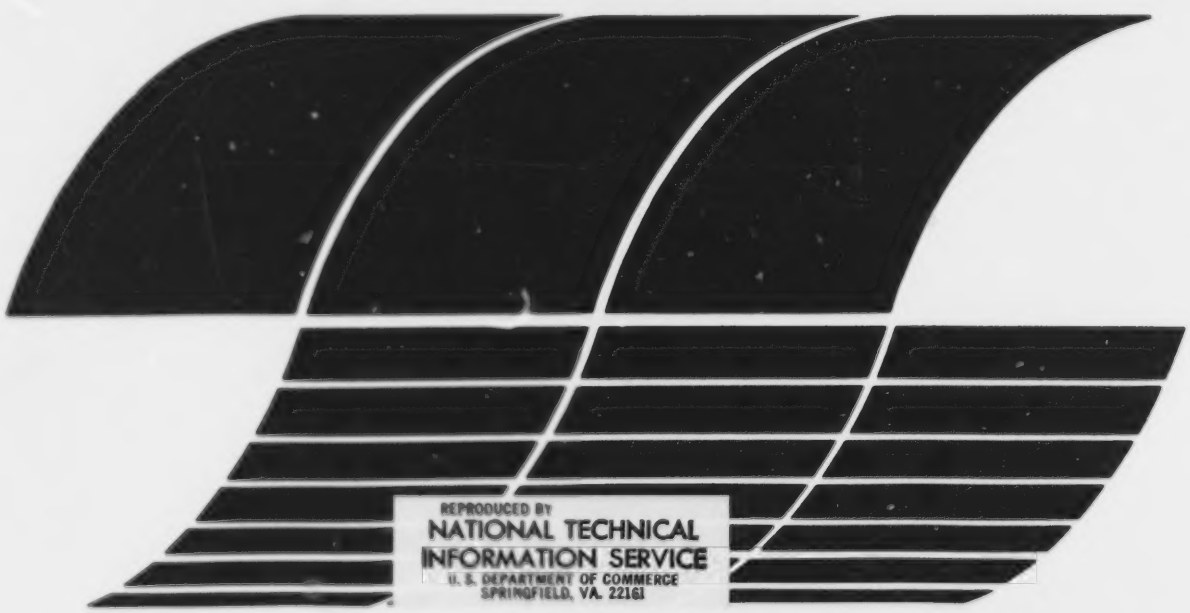

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ABSTRACT

This report is intended to provide useful tools for obtaining particle size distributions and graded penetration data from cascade impactor measurements. The programs calculate impactor aerodynamic cut points, total mass collected by the impactor, cumulative mass fraction less than for each stage, log-normal size distribution parameters for the data, and graded penetration. These programs are written specifically for the Texas Instruments SR-52 and TI-59 programmable calculators and the PC-100A printer. A general discussion of the program, an example problem, program listing, and user instructions are provided for each program.

CONTENTS

Abstract ii
Figures v
Tables vi
Nomenclature vii
Introduction 1
Notes on the Programs 2
SR-52 Program Set 3
General Discussion 3
Card 1 4
Card 2 5
Card 3 8
Card 4 8
Card 5 9
Card 6 10
Programming the Six Cards 11
Programming Card 1 11
Programming Card 4 11
Use of the Data Reduction Package 12
Example 1. Use of Data Reduction Package 12
TI-59 Program Set 23
General Discussion 23
Card 1 23
Example 2. Use of TI-59 Reduction Package 26
Example 3. Use of Programs to Convert Aerodynamic Diameter to Physical Diameter 30
Example 4. Calculation of Viscosity of Gas Mixtures 34
Cards 2, 3, and 4 (Calculation of Penetration as a Function of Particle Diameter with TI-59) 37
Example 5 39
Comparison of Graded Efficiency Calculated from Curve Fit and Spline Fit 47
Recommendations for Running Impactors 50
References 52

CONTENTS (Cont'd)

Appendix A.	User Instructions and Program Listing for SR-52 Data Reduction Programs	A-1
Appendix B.	User Instructions and Program Listing for TI-59 Impactor Data Reduction Package	B-1
Appendix C.	User Instructions and Program Listing for TI-59 Program to Convert Aerodynamic Diameter to Physical Diameter	C-1
Appendix D.	User Instructions and Program Listing for Program to Estimate Viscosity of Mixtures	D-1
Appendix E.	User Instructions and Program Listing for Spline Fit Program	E-1
Appendix F.	User Instructions and Program Listing for Calculation of Penetration as a Function of Particle Diameter for TI-59	F-1

FIGURES

Number		Page
1	Inlet cascade impactor data for example 1--use of SR-52 data reduction programs	17
2	Outlet cascade impactor data for example 1--use of SR-52 data reduction programs	19
3	Penetration as a function of particle diameter printer output for example 1--use of SR-52 data reduction programs	21
4	Contents of R_{40} through R_{52} for MRI impactor	25
5	Output from example 3--use of TI-59 data reduction package	28
6	Printer output for example 3--use of programs to convert d_A to d	33
7	Printer output for example 4--use of program to estimate viscosity	36
8	Printer output for example 5--use of TI-59 program to calculate penetration as a function of particle diameter	44
Appendix A		
	Impactor data reduction program listing card 1	A-4
	Impactor data reduction program listing card 2	A-6
	Impactor data reduction program listing card 3	A-8
	Impactor data reduction program listing card 4	A-9
	Impactor data reduction program listing card 5	A-11
	Log-normal penetration program listing	A-14
Appendix B		
	Program listing TI-59 cascade impactor data reduction--card 1	B-3
Appendix C		
	Program listing program to convert aerodynamic diameter to physical diameter	C-3
Appendix D		
	Program listing viscosity program	D-3

FIGURES (cont'd)

Number		Page
Appendix E		
	Spline fit card 1	E-3
	Spline fit card 2	E-8
Appendix F		
	Program listing Pt(d) program for TI-59	F-3

TABLES

Number		Page
1	Values of stage constants for MRI and University of Washington impactors	6
2	Values of constants for inverse normal function	9
3	Steps for using SR-52 data reduction package	13
4	Comparison of graded penetration calculated using log-normal fit, quadratic log-normal fit and spline fit on actual impactor data	48
5	Comparison of graded penetration calculated with spline and log-normal fits with actual graded penetrations from ESP model	49

NOMENCLATURE

A	-	Used to calculate Cunningham correction factor
A	-	Least-squares curve fit parameter in $y = A + Bx$
B	-	Least-squares curve fit parameter in $y = A + Bx$
C	-	Cunningham correction factor
C_i	-	Stage constant for i^{th} impactor stage
C_0	-	
C_1	-	Constants for rational approximation of inverse normal function
C_2	-	
C_3	-	
C_4	-	
C_5	-	
D_i	-	Diameter of holes for i^{th} impactor stage, cm
d	-	Particle diameter, μm
d_{50}	-	Physical impactor cut point, μm
d_{A50}	-	Aerodynamic impactor cut point, μmA
d_g	-	Mass mean diameter, μm
f_i	-	Cumulative mass fraction less than total mass for i^{th} impactor stage
$f_I(d)$	-	Inlet cumulative size distribution
$f_o(d)$	-	Outlet cumulative size distribution
K_{50i}	-	Inertial impaction parameter for 50% collection efficiency on the i^{th} impactor stage
M_i	-	Weight of particulate collected by i^{th} impactor stage, mg
M_T	-	Total weight of particulate collected by impactor, mg
N_i	-	Number of holes on the i^{th} impactor stage
P	-	Pressure, cm Hg
$Pt(d)$	-	Penetration of particles with diameter d

NOMENCLATURE (Cont'd)

$Pt(d)_{LN}$	-	Penetration of particles with diameter d calculated using linear log-normal fit
$Pt(d)_{LN}^2$	-	Penetration of particles with diameter d calculated using quadratic log-normal fit
$Pt(d)_M$	-	Penetration of particles with diameter d from electrostatic precipitator model
$Pt(d)_S$	-	Penetration of particles with diameter d calculated using spline fit
Q	-	Gas flow rate through impactor, l/m
R_{ij}	-	Storage register ij
r^2	-	Correlation coefficient
$S(x_i)$	-	Spline fit function evaluated at x_i
$S'(x_i)$	-	$d[S(x)]/dx$ evaluated at x_i
$S''(x_i)$	-	$d^2[S(x)]/dx^2$ evaluated at x_i
$S'''(x_i)$	-	$d^3[S(x)]/dx^3$ evaluated at x_i
T	-	Temperature, °C
t	-	Dummy variable used in inverse normal function calculation
t	-	Dummy variable used in spline fit program
V_i	-	Jet velocity for i^{th} stage, m/s
W_I	-	Inlet mass concentration, g/m^3
W_o	-	Outlet mass concentration, g/m^3
X	-	Inverse normal function
x	-	General variable
$\bar{x}$	-	Average value of x
y	-	General variable
$\bar{y}$	-	Average value of y
Z	-	Dummy variable

NOMENCLATURE (Cont'd)

μ	-	Gas viscosity, poise
λ	-	Gas mean free path
λ_o	-	Gas mean free path at 23°C
ρ	-	Particle density, g/cc
σ	-	Geometric standard deviation
σ_I	-	Inlet geometric standard deviation
σ_o	-	Outlet geometric standard deviation

INTRODUCTION

Cascade impactors are the major instrument for obtaining information on the instack particle size distribution before and after air pollution control equipment. Data reduction is tedious, time consuming, and generally requires access to a computer. Thus, there may be a long delay in obtaining reduced data after the measurements are made. Such delays can be especially troublesome in the field.

Recent advances in calculator technology make it possible to do much of the data reduction without a computer. Thus, reduced data can be available shortly after the measurements are made. The ability to examine reduced data shortly after the measurements are made is especially important in field tests. Trends and problems can be found while still in the field and corrective action can be taken to improve data taken later.

There are two sets of calculator programs in this report--one set for the Texas Instruments SR-52 calculator and a second set for the Texas Instruments TI-59 calculator. The programs in each set perform the following calculations:

1. Calculate aerodynamic cut points for each impactor stage.
2. Calculate total mass collected by the impactor.
3. Calculate the cumulative mass fraction less than for each stage.
4. Calculate the log-normal size distribution that best fits the data.
5. Calculate penetration as a function of particle diameter (graded penetration).

The methods used for the first four calculations are the same for both sets of programs. Graded penetration is calculated from the log-normal fit results in the SR-52 program set and from a spline fit to the impactor data in the TI-59 program set. A brief comparison of these two

methods for calculating graded penetration is included. Two additional TI-59 programs are also provided--one to convert aerodynamic diameter to physical diameter and one to estimate the viscosity of mixtures of gases.

NOTES ON THE PROGRAMS

In the user instructions and examples, a convention of underline letters or numbers has been adopted to denote the key or keys on the SR-52 or TI-59 keyboard which should be pressed to conduct the operation discussed. For example: in the instruction Press A, the underline indicates that the A button on the keyboard should be pressed. Storage registers are indicated by R_{ij}. For example: R_{01} refers to storage register 01.

The programs all make extensive use of the indirect recall and indirect store features of the SR-52 and TI 59. Thus, it is essential that the counter for the indirect recall and indirect store registers be set at the proper initial value and advanced at the required times. Anyone who wishes to modify the programs should remember that the programs as written depend on indirect recall and indirect store instructions.

Two of the SR-52 programs store data in registers that normally are used to store program instructions. This use of the program registers can cause problems with program execution if the magnetic cards containing the programs are read improperly.

Magnetic cards are read into the SR-52 calculator by:

Step	Procedure	Press
1	Enter side A	2nd rst 2nd read
2	Enter side B	2nd read

Instructions for reading magnetic cards into the TI-59 calculator are given in the appropriate user instructions.

The programs as written are for the Meteoroloy Research, Inc. (MRI) Cascade Impactor. The programs can be modified for use with other impactors provided:

1. Calibration data for the impactor are available.
2. Number of useful stages $\leq$ 7 (including filter).

SR-52 PROGRAM SET

GENERAL DISCUSSION

The SR-52 program set is contained on six magnetic cards that must be executed in the following order: Cards 1, 2, 3, 4, 5 for inlet data; Cards 1, 2, 3, 4, 5 for outlet data; and then Card 6 for combined inlet and outlet data.

Card 1 is used to calculate and store the aerodynamic cut diameter, d_{A50}, for each impactor stage. Impactor flow rate and impactor temperature are entered before the calculation.

Card 2 is used to calculate and store the total mass collected by the impactor, M_T, and the cumulative mass fraction less than total mass collected by each stage, f_i. Mass collected by each stage, M_i, is entered and printed before the calculation is performed.

Card 3 is used to print M_T, d_{A50}, and f_i.

Card 4 is used to transform the f_i so that a log-normal fit to the data can be calculated using Card 5.

Card 5 is used to calculate a least-squares best fit to the data transformed by Card 4. The log-normal parameters, mass geometric mean diameter, d_g, and geometric standard deviation, σ, are printed along with the least-squares fit parameters, A and B for $y = A + Bx$, and the correlation coefficient, r^2.

Card 6 is used to calculate and print the graded penetration for two log-normal particle size distributions. Inlet mass concentration, W_I, outlet mass concentration, W_o, inlet geometric standard deviation, σ_I, outlet geometric standard deviation, σ_o, inlet mass mean diameter, d_{gI}, and outlet mass mean diameter, d_{go}, are entered before the calculation is performed.

The programs on each card are discussed in detail in the next sections.

Card 1

Card 1 is used to enter the impactor flow rate, Q, in either ft^3/min or l/min and the impactor temperature, T, in either °F or °C. The program on the card then calculates d_{A50i} in μmA* for each stage. The d_{A50i} are stored in the calculator for use by other programs.

d_{A50i} is given by

$$d_{A50i} = \sqrt{\frac{0.135\ \mu\pi\ D_i^3 N_i K_{50i}}{Q \times 10^{-8}}} \qquad (1)$$

where μ = the viscosity of the gas in poise

D_i = the diameter of the holes on the i^{th} stage in cm

N_i = number of holes on the i^{th} stage

Q = gas flow rate in l/m

K_{50i} = inertial impaction parameter for 50% collection efficiency on the i^{th} stage

$K_{50i} = d^2_{50i}\ C\rho\ V_i / 9\mu\ D_i \times 10^8$

d_{50i} = physical cut diameter, μm

C = Cunningham correction factor

ρ = particle density

V_i = jet velocity for i^{th} stage, m/s

*The convention to denote aerodynamic diameters by μmA will be used throughout this report.

The gas viscosity used in the program is for air and is estimated by

$$\mu = 1.68 \times 10^{-4} + 2.292 \times 10^{-7} \times (1.8\,T + 32) \quad (2)$$

where μ is in poise and T is in °C.

The value for K_{50i} should be based on experimentally determined calibration curves. If such curves are not available $K_{50i} = 0.2$ can be used.

Equation 1 can be rewritten as

$$d_{A50i} = \sqrt{C_i \mu / (Q \times 10^{-8})} \quad (3)$$

where C_i = stage constant for the i^{th} stage,

$$C_i = 0.135\ \pi Di^3 N_i K_{50i} \quad (4)$$

C_i must be calculated at the time the calculator is first programmed and is stored in registers R_{91} - R_{97}. When a program with C_i stored in these registers is recorded on a magnetic card, the C_i are recorded on the card and become a permanent part of the program.

C_i for the MRI and University of Washington cascade impactors are shown in Table 1.

To use the program with an impactor other than the MRI impactor, store the appropriate stage constants in R_{91} through R_{97}.

Card 2

Card 2 is used to enter the mass collected on the i^{th} stage, M_i, and to calculate M_T and f_i. The M_i are entered in order of i = 1 to i = N where i = 1 is the stage with the largest d_{50i} and i = N is the filter.

Table 1. VALUES OF STAGE CONSTANTS FOR MRI AND UNIVERSITY OF WASHINGTON IMPACTORS

Stage	MRI Ci	University of Washington Ci	Store in
1	5.4069×10^{-2}	7.4123×10^{-2}	R_{91}
2	6.8611×10^{-2}	9.3954×10^{-2}	R_{92}
3	2.1484×10^{-2}	1.3376×10^{-2}	R_{93}
4	3.8666×10^{-3}	1.7759×10^{-3}	R_{94}
5	1.0147×10^{-3}	1.8378×10^{-3}	R_{95}
6	3.5065×10^{-4}	4.2206×10^{-4}	R_{96}
7	2.2899×10^{-4}	1.0104×10^{-4}	R_{97}

MRI stage constants for stages 4, 5, 6, and 7 are based on EPA/IERL-RTP/ Particulate Technology Branch impactor calibration data. University of Washington stage constants and MRI stage constants for stages 1, 2, and 3 are based on Southern Research Institute calibration data.

The total mass collected is given by

$$M_T = \sum_{i=1}^{N} M_i \tag{5}$$

The cumulative fraction less than the total collected on the i^{th} stage, f_i, is given by

$$f_i = \left\{ \sum_{j=0}^{j=i-1} \frac{M_j}{M_T} \right. \tag{6}$$

where $j = 0$ is the filter.

The f_i are stored in the calculator for later use.

The cut points for the first two stages of the MRI impactor overlap. The masses collected by these two stages should be manually added together. The sum $M_1 + M_2$ is then entered into the calculator and is automatically attributed to the second stage in the data reduction program. The first two stages of the University of Washington impactor also overlap and must be handled in the same way as the first two stages of the MRI impactor.

The fact that the mass collected on the first two stages are added together means that there are seven masses entered. These seven M_i are used to calculate six cumulative fraction less than values which are stored for later use. The number of cumulative fraction less than values that can be stored is limited to six. If the impactor being used has more than six useful stages plus filter, the mass collected by the extra stages can be lumped with that of the top stage. For example, if there are seven useful stages 1, 2, 3, 4, 5, 6, 7, plus filter; the mass collected by stage 1 can be added to that collected by stage 2.

Card 3

Card 3 recalls M_T, f_i, and d_{A50i} from memory and prints them in the following order: M_T, d_{A501}, f_1,....d_{A506}, f_6.

Card 4*

The f_i are transformed to normal coordinates by use of the inverse normal integral, X, based on the cumulative mass fraction f_i

$$f(X) = \int_{-\infty}^{X} \frac{e^{-t^2/2}}{\sqrt{2\pi}}\, dt \qquad (7)$$

where

$$f(-\infty) = 0$$
$$f(0) = 0.5$$
$$f(+\infty) = 1.0$$

Hastings[1] gives a rational approximation that can be used to calculate X

$$X = t + \left[\frac{C_0 + C_1 + C_2 t^2}{1 + C_3 t + C_4 t^2 + C_5 t^3}\right] + \text{error of order } \varepsilon \qquad (8)$$

$|\varepsilon| \leq 0.00045$

$$\text{where } t = \sqrt{\ln \left(\frac{1}{1-f}\right)^2} \quad \text{for} \quad \begin{matrix} f < 1 \\ f > 0.5 \end{matrix} \qquad (9)$$

The calculator program accounts for all f_i since

$$X(f_i = m) = X(f_i = 1 - m) \text{ for } m < 0.5 \text{ by symmetry.} \qquad (10)$$

For example $X(f_i = 0.4) = -X(f_i = 0.6)$

The constants C_0 through C_5 are stored in registers R_{92} through R_{97}. The values of C_0 through C_5 are given in Table 2.

*Much of the original work for the program on Card 4 is due to H. F. Barbarika of Air Pollution Technology, Inc.

Table 2. VALUES OF CONSTANTS FOR INVERSE NORMAL FUNCTION

C_0	=	2.515517 stored in R_{92}
C_1	=	0.802853 stored in R_{93}
C_2	=	0.010328 stored in R_{94}
C_3	=	1.432788 stored in R_{95}
C_4	=	0.189269 stored in R_{96}
C_5	=	0.001308 stored in R_{97}

The first time the program is read onto a magnetic card with C_0 through C_5 stored in R_{92} through R_{97}, the constants become a permanent part of the program.

Card 5

Card 5 is used to determine the log-normal size distribution parameters for the data entered previously. The log-normal parameters, d_{Ag} and σ, are determined by constructing a least-squares straight line through the data transformed on Card 4. The fitted line is of the form

$$y = A + Bx \tag{11}$$

The constants A and B are determined by

$$A = \bar{y} - B\bar{x} \tag{12}$$

$$B = \frac{\Sigma(xy) - \bar{y}\,\Sigma x}{\Sigma(x^2) - (\Sigma x)^2/N} \tag{13}$$

where N = the number of data points

$\bar{x}$ = $\Sigma x/N$ is the average value of x and

$\bar{y}$ = $\Sigma y/N$ is the average value of y

The log-normal parameters are given by

$$d_g = \exp(-A/B) \tag{14}$$

$$\sigma = \exp(1/B) \tag{15}$$

The correlation coefficient r^2 for the curve fit is given by

$$r^2 = \left(b \sqrt{\frac{\Sigma(x^2) - (\Sigma x)^2}{\Sigma(y^2) - (\Sigma y)^2/N}} \right)^2 \tag{16}$$

A, B, r^2, d_{Ag}, and σ are all printed.

Card 6

Card 6 calculates and prints penetration as a function of particle diameter (the graded penetration) for two log-normal size distributions.

The penetration of particles of diameter d, Pt(d), is defined as

$$Pt(d) = \frac{W_o}{W_I} \left[\frac{df_o(d)/dd}{df_I(d)/dd} \right] \tag{17}$$

where W_o = mass concentration at outlet
W_I = mass concentration at inlet
$f_o(d)$ = outlet cumulative size distribution
$f_I(d)$ = inlet cumulative size distribution

For a log-normal distribution:

$$f(d) = \int_{-\infty}^{d} \frac{1}{2\pi/d\ln\sigma} \exp \left[\frac{-\ln^2(d/d_g)}{2 \ln^2\sigma} \right] dd \tag{18}$$

Pt(d) becomes

$$Pt(d) = \frac{W_o}{W_I} \frac{\ln\sigma_I}{\ln\sigma_o} \exp (Z_I^2 - Z_o^2)/2 \tag{19}$$

where $Z = \frac{\ln d - \ln d_g}{\ln\sigma}$

The program solves equation (19) for the range d = 0.1 to 20 μm and prints d, Pt(d), and 1-Pt(d) (the efficiency) in 0.1 μm steps for $0.1 \leq d < 1$ and

in 1 μm steps for $1 \leq d \leq 20$. The printed results are not reliable when d is outside the range of the impactor data.

The log-normal penetrations calculated by this program are a good representation of the data when the product of the inlet and outlet correlation coefficients, $r^2_{in} \times r^2_{out}$, exceeds 0.985. When the r^2 product is less than 0.985 the calculated penetrations are still useful for determining trends.

PROGRAMMING THE SIX CARDS

Programming the cards is straightforward except for Cards 1 and 4. Data registers that normally store program instructions are used to store constants used in the calculations for Cards 1 and 4. Special care must be taken to ensure that the constants are stored in the proper registers before the magnetic cards are recorded.

Programming Card 1

Turn the calculator on. Press LRN to put the calculator in the learn mode. Enter the Impactor d_{A50} program as listed in the program listing. After the last instruction is entered, press LRN to return the calculator to calculate mode. Enter stage constants, one at a time, and store them in the appropriate registers, see Table 1. After the last stage constant is stored, record both sides of a magnetic card using following steps: press 2nd rst, insert side 1, press INV 2nd READ, insert side 2, and then press INV 2nd READ.

Programming Card 4

Turn the calculator on. Press LRN to put the calculator in the learn mode. Enter the Inverse Normal Function program as listed in the program listing. After the last instruction is entered, press LRN to return the calculator to calculate mode. Enter C_0 through C_5, one at a time, and store them in the appropriate registers, see Table 2.

Record the program on both sides of a magnetic card by following the same procedure used for Card 1.

USE OF THE DATA REDUCTION PACKAGE

The step by step procedure for using the data reduction package is given in Table 3. Use of the package is demonstrated in Example 1.

Example 1. Use of Data Reduction Package

An MRI impactor was used to obtain the following data. Use the data reduction package to reduce the data.

Inlet		Outlet
Q	= 9.569 l/m	Q = 33.01 l/m
T	= 92°C	T = 92°C
$M_1 + M_2$	= 0.0146 mg	0.00005 mg
M_3	= 0.0199	0.0010
M_4	= 0.0273	0.0025
M_5	= 0.0080	0.0014
M_6	= 0.0021	0.0007
M_7	= 0.0005	0.0009
M_8(filter)	= 0.0003	0.0014
W_{IN}	= 0.3804 mg/l	W_o = 0.00072 mg/l

Table 3. STEPS FOR USING SR-52 DATA REDUCTION PACKAGE

Step	Procedure	Enter	Press	Display	Print
1	Read sides A and B of Card 1				
2	Check to see if card read properly		RCL 92	Constant for 1st stage	
3	Enter T	T°C	A	T°C	
	or	T°F	2nd A'	T°C	
4	Enter Q	Q l/min	B	Q l/min	
	or	cfm	2nd B	Q l/min	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.0000	
7	Calculate d_{A50i}		D	0.0000	
8	Read sides A and B of Card 2				
9	Initialize		E	0.0000	
10	Enter M_i	M_1	A	1.0000	M_1
		M_2	A	2.0000	M_2
		.		.	.
		.		.	.
		.		.	.
		M_{filter}	A	7.0000	M_8

Note: For the MRI and University of Washington impactors, M_1 = the sum of the mass collected on the first two stages. M_1 and M_2 must be added before the data are entered.

11	Calculate f_i	B	0.0000	
12	Read Side A of Card 3			
13	Print M_T, $f_i d_{A50i}$		f_6	M_T
				d_{A501}
				f_1
				.
				.
				.
				d_{A506}
				f_6

Table 3. STEPS FOR USING DATA REDUCTION PACKAGE (Cont'd)

Step	Procedure	Enter	Press	Display	Print
14	Read Card 4 sides A and B				
15	Initialize		E	8.0000	
16	Transform f_i		A		
17	Read Card 5 sides A and B				
18	Initialize		E	0.0000	
19	Calculate log-normal parameters		A	σ	A
					B
					r^2
					d_g
					σ
20	Read Card 6 sides A and B			2nd rst	
				INV READ	
				INV READ	
21	Enter W_I	W_I	A		0.10000
22	Enter W_o	W_o	2nd A'		W_o
23	Enter σ_I	σ_I	B		ln σ_I
24	Enter σ_o	σ_o	2nd B'		ln σ_o
25	Enter d_{gI}	d_{gI}	C		lnd_{gI}
26	Enter d_{go}	d_{go}	2nd C'		ln d_{go}
27	Calculate Pt(d)		D		.
					Pt(d)
					1-Pt(d)
					0.1
					.
					.
					.
					Pt(d)
					1-Pt(d)
				9999.00000	20.0

Solution

Step	Procedure	Enter	Press	Display	Print
	Do inlet calculations		2nd rst READ		
1	Read Card 1		2nd READ		
2	Check to see if read correctly		RCL 91	.054069	
3	Enter T °C	92	A	92	
4	Enter Q l/m	9.5696	B	9.5696	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.000	
7	Calculate d_{A50i}		D	0.00000	
8	Read Card 2		2nd rst 2nd READ		
9	Initialize		E	0.000000	
	Put calculator in fix display mode		INV EE	0.0000	
10	Enter $M_1 + M_2$	0.0146	A	1	0.0146
	M_3	0.0199	A	2	0.0199
	M_4	0.0273	A	3	0.0273
	M_5	0.008	A	4	0.0080
	M_6	0.0021	A	5	0.0021
	M_7	0.0005	A	6	0.0005
	M_8	0.0003	A	7	0.0003
11	Calculate f_i		B	0.0000	
12	Read Card 3 side A only		2nd rst 2nd READ		
13	Print results		A	0.0028	0.0727
					12.3662
					0.7992
					6.9199
					0.5254
					2.9356
					0.1499
					1.5039
					0.0399
					0.8840
					0.0110

Step	Procedure	Enter	Press	Display	Print
					0.7144
					0.0041
14	Read Card 4		2nd rst 2nd READ		
			2nd READ		
15	Initialize		E	8.0000	
16	Transform f_i		A	0.0000	
17	Read Card 5		2nd rst 2nd READ		
			2nd READ		
18	Initialize		E	0.0000	
19	Calculate		A	2.3102	1.1943
					-2.2263
					0.9978
					6.4505
					2.3102

A sample print out for inlet calculations is shown in Figure 1.

Repeat for Outlet

Step	Procedure	Enter	Press	Display	Print
1	Read Card 1		2nd CMS		
			2nd rst		
			2nd READ		
			2nd READ		
			clr		
2	Check to see if card read correctly		RCL 91	0.054069	
3	Enter T °C	92	A	92.0000	
4	Enter Q l/m	33.01	B	33.0100	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.0000	
7	Calculate d_{A50i}		D	0.0000 00	
8	Read Card 2 and change display		2nd rst 2nd READ		
	to fix mode		2nd READ INV EE	0.0000	

```
 0.0146      PRT
 0.0199      PRT
 0.0273      PRT
 0.0080      PRT
 0.0021      PRT
 0.0005      PRT
 0.0003      PRT

 0.0727      PRT

12.3662      PRT
 0.7992      PRT

 6.9199      PRT
 0.5254      PRT

 2.9356      PRT
 0.1499      PRT

 1.5039      PRT
 0.0399      PRT

 0.8840      PRT
 0.0110      PRT

 0.7144      PRT
 0.0041      PRT

 1.1943      PRT
-2.2263      PRT
 0.9978      PRT
 6.4505      PRT
 2.3102      PRT
```

Figure 1. Inlet Cascade Impactor Data for Example 1--Use of SR-52 Data Reduction Programs

Step	Procedure	Enter	Press	Display	Print
9	Enter $M_1 + M_2$	0.00005	A	1.0000	0.0001 (0.00005 rounded to 0.0001 because of printer command in Card 1)
	M_3	0.001	A	2	0.0010
	M_3	0.0025	A	3	0.0025
	M_4	0.0014	A	4	0.0014
	M_5	0.0007	A	5	0.0007
	M_6	0.0009	A	6	0.0009
	$M_{8(filter)}$	0.0014	A	7	0.0014
					0.0080
					.
					.
					.
10	Calculate f_i		B	0.0000	2.5213
11	Read Card 3 side A only		2nd rset 2nd READ	7	
12	Print outlet results		A		
13	Read Card 4 sides A and B		2nd rset 2nd READ 2nd READ		
14	Initialize		E	8.0000	
15	Transform		A	0.0000	
16	Read Card 5 sides A and B		2nd rset 2nd READ 2nd READ		
17	Initialize		E	0.0000	1.0813
18	Calculate		A	3.3014	0.0077
					0.9384
					0.9929
					2.5213

Printer output for the outlet calculations is shown in Figure 2. Note that r^2 for inlet is 0.9978 and is 0.9384 for outlet.

```
0.0001      PRT
0.0010      PRT
0.0025      PRT
0.0014      PRT
0.0007      PRT
0.0009      PRT
0.0014      PRT

0.0080      PRT

6.6583      PRT
0.9937      PRT

3.7258      PRT
0.8679      PRT

1.5806      PRT
0.5535      PRT

0.8097      PRT
0.3774      PRT

0.4760      PRT
0.2893      PRT

0.3847      PRT
0.1761      PRT

1.0813      PRT
0.0077      PRT
0.9384      PRT
0.9929      PRT
2.5213      PRT
```

Figure 2. Outlet Cascade Impactor Data for Example 1 - Use of SR-52 Data Reduction Programs

Now calculate Pt(d)

Step	Procedure	Enter	Press	Display	Print
1	Read Card 6		2nd rst		
			2nd READ		
			2nd READ		
			2nd Cms		
			Clr		
			2nd Fix 5	0.00000	
2	Enter W_I	.3804	A	0.10000	
3	Enter W_o	.00072	2nd A	0.00072	
4	Enter σ_I	2.3102	B	0.83733	
5	Enter σ_o	2.5213	2nd B'	0.92477	
6	Enter d_{gI}	6.4505	C	1.86416	
7	Enter d_{go}	0.9929	2nd C'	-0.00713	
8	Calculate Pt(d)		D		18.75795*
					-17.75795
					0.10000
					.
					.
					.
					.
					0.00002
					0.99998
					20.00000
				9999.00000	

For entire printer output see Figure 3.

*The first five or six values of Pt(d) are unreliable because extrapolation of the data was used to calculate them.

18.75795	PRT		
-17.75795	PRT	0.00342	PRT
0.10000	PRT	0.99658	PRT
		2.00000	PRT
2.08446	PRT		
-1.08446	PRT	0.00127	PRT
0.20000	PRT	0.99873	PRT
		3.00000	PRT
0.61050	PRT		
0.38950	PRT	0.00065	PRT
0.30000	PRT	0.99935	PRT
		4.00000	PRT
0.26207	PRT		
0.73793	PRT	0.00039	PRT
0.40000	PRT	0.99961	PRT
		5.00000	PRT
0.13801	PRT		
0.86199	PRT	0.00026	PRT
0.50000	PRT	0.99974	PRT
		6.00000	PRT
0.08250	PRT		
0.91750	PRT	0.00019	PRT
0.60000	PRT	0.99981	PRT
		7.00000	PRT
0.05376	PRT		
0.94624	PRT	0.00014	PRT
0.70000	PRT	0.99986	PRT
		8.00000	PRT
0.03728	PRT		
0.96272	PRT	0.00011	PRT
0.80000	PRT	0.99989	PRT
		9.00000	PRT
0.02709	PRT		
0.97291	PRT	0.00009	PRT
0.90000	PRT	0.99991	PRT
		10.00000	PRT
0.02043	PRT		
0.97957	PRT		
1.00000	PRT		

Figure 3. Penetration as a Function of Particle Diameter
Printer Output for Example 1 - Use of SR-52
Data Reduction Programs

```
 0.00007      PRT
 0.99993      PRT
11.00000      PRT

 0.00006      PRT
 0.99994      PRT
12.00000      PRT

 0.00005      PRT
 0.99995      PRT
13.00000      PRT

 0.00004      PRT
 0.99996      PRT
14.00000      PRT

 0.00004      PRT
 0.99996      PRT
15.00000      PRT

 0.00003      PRT
 0.99997      PRT
16.00000      PRT

 0.00003      PRT
 0.99997      PRT
17.00000      PRT

 0.00003      PRT
 0.99997      PRT
18.00000      PRT

 0.00002      PRT
 0.99998      PRT
19.00000      PRT

 0.00002      PRT
 0.99998      PRT
20.00000      PRT
```

Figure 3. (Cont'd)

TI-59 PROGRAM SET

GENERAL DISCUSSION

The TI-59 program set is contained on five cards. Four cards are used to store program instructions and the fifth card is used to store the impactor stage constants and the constants for the log-normal transformation. The Master Library Module is used as a subroutine in the data reduction program set.

Card 1 is used to perform all the calculations performed by Cards 1, 2, 3, 4, and 5 in the SR-52 program set. The card containing the stage constants is used in conjunction with Card 1.

Cards 2, 3, and 4 are used to calculate the graded penetration curve and are used in the following order: Cards 2 and 3 for inlet data, Cards 2 and 3 for outlet data, and then Card 4.

Card 2 is used to enter d_{50i} and f_i and to set up a spline fit calculation.

Card 3 is used to complete the spline fit calculation of df_i/dd.

Card 4 is used to calculate Pt(d) from the values of df_i/dd calculated by Cards 2 and 3.

Two additional sets of programs--one to convert aerodynamic diameter to physical diameter and one to calculate the viscosity of mixtures of gases--are included.

The use of all cards is discussed below.

CARD 1

Card 1 in the TI-59 data reduction package replaces Cards 1, 2, 3, 4 and 5 in the SR-52 package. The programs on Card 1 solve the same

equations using the same methods as are used in the SR-52 package. The discussion of equations and methods of solution will not be repeated here.

A data card which contains the impactor stage constants and the constants for the log-normal transformation are used with Card 1. This data card is recorded in advance. The steps necessary for recording the data card are:

1. Store impactor stage constants in R_{40} through R_{46}.

2. Store constants for log-normal fit in R_{47} through R_{52}.

3. Record the constants on magnetic card as follows:

   Enter 3
   Press 2nd Write
   Pass a magnetic card through the calculator.

The memory contents for the MRI Impactor are shown in Figure 4. The steps for entering the cards are shown below.

Step	Procedure	Enter	Press	Display
1	Enter side 1 of card containing program		Clr	1
2	Enter side 2 of card containing program		Clr	2
3	Enter card with constants		Clr	3

The use of the programs contained on Card 1 is demonstrated by Example 2.

Value of Constant	Register
0.054069	40
0.068611	41
0.021484	42
C.0038666	43
C.0010147	44
0.00035065	45
0.00022899	46
2.515517	47
0.802853	48
0.010328	49
1.432788	50
0.189269	51
0.001308	52

Figure 4. Contents of R_{40} through R_{52} for MRI Impactor

Example 2. Use of TI-59 Reduction Package

The following data were collected with an MRI Impactor:

T	=	177°C
P	=	76 cm Hg
Q	=	11.64 l/m
$M_1 + 2$	=	7.1 mg
M_3	=	4.9
M_4	=	4.6
M_5	=	1.8
M_6	=	0.8
M_7	=	0.3
M_{filter}	=	0.3

Use the TI-59 program to reduce the data.

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of card containing program		Clr	1	
2	Enter side 2 of card containing program		Clr	2	
3	Enter card containing constants		Clr	3	
4	Enter data		A	370064	T=
	T °C	177	R/S		177
	P cm Hg	76			P=
					76.00
				340064	Q=
	Q l/m	11.64	R/S	3013363600	11.64
					MASS
	$M_1 + M_2$	7.1	R/S	3013363600	7.1

Step	Procedure	Enter	Press	Display	Print
					MASS
	M_3	4.9	R/S	3013363600	4.9
					MASS
	M_4	4.6	R/S	3013363600	4.6
					MASS
	M_5	1.8	R/S	3013363600	1.8
					MASS
	M_6	0.8	R/S	3013363600	0.8
					MASS
	M_7	0.3	R/S	3013363600	0.3
					MASS
	M_{filter}	0.3	R/S		0.3

Program will run for 2 minutes then printing will start

D50
.6989891358
FI
.0151515152
For entire Printout see Figure 5
.
.
.
SIGMA
3.251912896

3.251912896

Printout for this example is shown in Figure 5.

Note that the impactor data reduction program results are for aerodynamic particle diameter. The aerodynamic particle diameter is appropriate for describing the performance of devices which collect particles by inertial impaction; e.g., venturi scrubbers. However, the aerodynamic diameter is not appropriate for many situations; e.g., for describing the performance of

```
T =
 177.
P =
  76.
Q =
 11.64
MASS
  7.1
MASS
  4.9
MASS
  4.6
MASS
  1.8
MASS
  0.8
MASS
  0.3
MASS
  0.3
 D50
.6989891358
 FI
.0151515152
 D50
.8649661038
 FI
.0303030303
 D50
1.471400832
 FI
.0707070707
 D50
2.872280107
 FI
.1616161616
 D50
6.770484356
 FI
.3939393939
 D50
12.09926647
 FI
.6414141414
   A
-1.823399103
   B
.8480013495
R**2
0.995740151
  DG
8.586844903
SIGMA
3.251912896
```

Figure 5. Output from Example 3--Use of TI-59 Data Reduction Package

electrostatic precipitators. In such cases the physical particle diameter is needed.

The physical particle diameter, d, is given by

$$d = d_A / \sqrt{\rho C} \tag{20}$$

where ρ = the particle density and
C = Cunningham correction factor.

The Cunningham correction factor can be calculated from the mean free path of the gas, λ, and the particle diameter d from

$$C = 1 + 2A\frac{\lambda}{d} \tag{21}$$

where

$$A = 1.246 + 0.42 \exp(-0.87d/2\lambda) \tag{22}$$

The mean free path of the gas, λ, can be calculated from

$$\lambda = \lambda_o \left(\frac{76}{P}\right)\left(\frac{T°K}{296.2}\right) \tag{23}$$

where

λ_o = mean free path at 23°C and 76 cm Hg = 0.0653 μm for air
P = barometric pressure cm Hg
T = temperature °K

Equation (20) can be solved for d by trial and error.

The TI-59 program for calculating d is given in Appendix C. The program converts d_A to d*, prints d_A and corresponding d, prints d_i and f_i, and

*The tolerance for the trial and error solution of equation (20) is $|d_{i+1} - d_i|/d_i < 0.001$.

calculates and prints the log-normal fit parameters d_g, σ along with A and B for $y = A + Bx$, and the correlation coefficient r^2.

The use of this program is illustrated in Example 3.

Example 3. Use of Programs to Convert Aerodynamic Diameter to Physical Diameter

The following data were collected with an MRI impactor.

T	=	100°C
P	=	76 cm Hg
Q	=	16 l/m
$M_1 + M_2$	=	8.0 mg
M_3	=	5.0 mg
M_4	=	4.5 mg
M_5	=	2.0 mg
M_6	=	0.9 mg
M_7	=	0.45 mg
M_8	=	0.3 mg
ρ	=	2.4 g/cc

Use the TI-59 programs to reduce the data for both aerodynamic and physical particle diameters.

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of data reduction card		Clr	1	
2	Enter side 2 of data reduction card		Clr	2	
3	Enter card containing constants		Clr	3	
4	Enter data		A	370064	T=
	T °C	100	R/S		100

Step	Procedure	Enter	Press	Display	Print
				330064	P=
	P cm Hg	76	R/S	340064	76
					Q=
	Q l/m	16	R/S	30133663600	16
					MASS
	$M_1 + M_2$	8.0	R/S	30133663600	8.
					MASS
	M_3	5.0	R/S	30133663600	5.
					MASS
	M_4	4.5	R/S	30133663600	4.5
					MASS
	M_5	2.0	R/S	30133663600	2.
					MASS
	M_6	0.9	R/S	30133663600	0.9
					MASS
	M_7	0.45	R/S	30133663600	0.45
					MASS
	M_{filter}	0.3	R/S		0.3

Program will run for about 2 minutes then printing will start

D50
.5567597984
.
.
.
SIGMA
3.372605753

			3.372605753	
5	Enter side 1 of card to calculate d from d_A	CLR	1	
6	Enter side 2 of card to calculate d from d_A	CLR	2	
7	Begin calculation	A	3745710000	Density?
	Enter 2.4	R/S		2.4

Step	Procedure	Enter	Press	Display	Print
					9.637324556 DA
					6.118139795 DP
					.
					.
					.

Printer output for this example is given in Figure 6.

As can be seen from equation (1), d_{A50} is a function of gas viscosity. The TI-59 program uses a relationship developed for air to estimate gas viscosity at impactor temperature. If the gas being sampled has a composition significantly different from that of air, the viscosity used in the program will be in error. In many cases, especially when quick data reduction at field tests is needed, the error in d_{A50} caused by using viscosity of air is not too important. However, final data reduction should be performed using the best possible estimate of the viscosity of the actual gas being sampled.

The program given in Appendix D can be used to estimate the viscosity of gas mixtures. Input data required for this program are: number of components and the viscosity, molecular weight and mole fraction of each pure component. The viscosity calculated from this program can be used in the impactor program by modifying subroutine A'of the impactor program, as follows:

1. Read TI-59 data reduction program card.
2. Press GTO 2nd A'
3. Press Learn
4. Starting at program step 339, enter the value of viscosity calculated from viscosity program
5. After last number for viscosity is entered, press INV SBR
6. Press Learn
7. Record modified program
8. Reduce data following instructions for TI-59 programs.

```
T =
 100.
P =
  76.
Q =
  16.
MASS
   8.
MASS
   5.
MASS
 4.5
MASS
   2.
MASS
 0.9
MASS
0.45
MASS
 0.3
 D50
.5567597984
 FI
.0141843972
 D50
.6889640038
 FI
.0354609929
 D50
1.172002237
 FI
.0780141844
 D50
2.287832545
 FI
.1725768322
 D50
5.392835614
 FI
.3853427896
 D50
9.637324556
 FI
0.621749409
  A
-1.602678119
  B
.8225810569
R**2
0.992469079
  DG
 7.017119575
SIGMA
 3.372605753
```

```
DENSITY?
  2.4

9.637324556     DA
6.118139795     DP

5.392835614     DA
3.379058333     DP

2.287832545     DA
1.376807932     DP

1.172002237     DA
.6590790717     DP

.6889640038     DA
.3488621786     DP

.5567597984     DA
0.264398662     DP

 D50
0.264398662
 FI
.0141843972
 D50
.3488621786
 FI
.0354609929
 D50
.6590790717
 FI
.0780141844
 D50
1.376807932
 FI
.1725768322
 D50
3.379058333
 FI
.3853427896
 D50
6.118139795
 FI
0.621749409
  A
-1.125663512
  B
0.749240985
R**2
.9926892225
  DG
 4.492481161
SIGMA
 3.798795567
```

Figure 6. Printer Output for Example 3--Use of Programs to Convert d_r to d

The use of the viscosity program is illustrated in Example 4.

Example 4. Calculation of Viscosity of Gas Mixtures

Calculate the viscosity of a mixture of hydrogen, H_2, and carbon dioxide, CO_2, at 21°C.

Component	Viscosity	Molecular Weight	Mole Fraction
H_2	0.0876 cp	2	0.413
CO_2	0.148 cp	44	0.587

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of viscosity program		CLR	1	
	Read side 2 of viscosity program		CLR	2	
2	Begin calculation		A	3171	N?
3	Enter number of components	2	R/S		2.0000
					I = 2.0000
				42243671.00	VIS?
	Enter viscosity of H_2	0.0876	R/S		0.0876
				3043710000	MW?
	Enter molecular weight of H_2	2	R/S		2.0000
				44710000	X?
	Enter mole fraction of H_2	.413	R/S		0.4130
					I 1.0000
				42243671.00	VIS?
	Enter viscosity of CO_2	.1480	R/S		0.1480
			3043710000		MW?

Step	Procedure	Enter	Press	Display	Print
	Enter molecular weight of CO_2	44	R/S		44.0000
				4471.0000	X?
	Enter mole fraction of CO_2	.587	R/S		0.5870
	After about 30 sec calculator will print viscosity of mixture			0.1501	0.1501 VIS

Printer output for this example is shown in Figure 7.

```
   N?
 2.0000

 I=
 2.0000
VIS?
 0.0876
MW?
 2.0000
 X?
 0.4130

 I=
 1.0000
VIS?
 0.1480
MW?
44.0000
 X?
 0.5870

 0.1501       VIS
```

Figure 7. Printer Output for Example 4--Use of Program to Estimate Viscosity

CARDS 2, 3, AND 4 (CALCULATION OF PENETRATION AS A FUNCTION OF PARTICLE DIAMETER WITH TI-59)

The derivative of the cumulative fraction less than function must be calculated in order to calculate Pt(d). The derivative can be calculated either from a curve fit to the impactor data or from differentials calculated from the tabular impactor data. The curve fit method is discussed in the SR-52 section of this report. The calculation of differentials from tabular data is discussed in this section.

A spline function gives the smoothest possible curve through data and gives the best estimate of the derivatives for the tabular data.[2] The general theory of spline functions and how to fit data with them is discussed in Reference 3 and will not be covered in this report. The Spline Function Program given in Reference 3 has been programmed for the TI-59. The program listing is given in Appendix E. Only the use of the program will be discussed in this report. This program uses numerical relaxation to solve the following system of six equations:

$$S''(X_1) = 0 \tag{24}$$

$$-S''(X_2) - b_2\, S''(X_1) - (1/2 - b_2)S''(X_3) + g_2 \leq \varepsilon \tag{25}$$

$$-S''(X_3) - b_3\, S''(X_2) - (1/2 - b_3)S''(X_4) + g_3 \leq \varepsilon \tag{26}$$

$$-S''(X_4) - b_4\, S''(X_3) - (1/2 - b_4)S''(X_5) + g_4 \leq \varepsilon \tag{27}$$

$$-S''(X_5) - b_5\, S''(X_4) - (1/2 - b_5)S''(X_6) + g_5 \leq \varepsilon \tag{28}$$

$$S''(X_6) = 0 \tag{29}$$

where

$$S''(x_i) = \frac{2}{x_{i+1} - x_{i-1}} \left[\frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} - \frac{(y_i - y_{i-1})}{(x_i - x_{i-1})} \right], \tag{30}$$

$$b_i = 1/2\, \frac{(x_i - x_{i-1})}{(x_{i+1} - x_{i-1})} \tag{31}$$

$$g_i = \frac{3}{x_{i+1} - x_{i-1}} \left[\frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} - \frac{(y_i - y_{i-1})}{(x_i - x_{i-1})} \right] \quad (32)$$

for $2 \leq i \leq 5$

and ε is a user specified tolerance (0.00001 is adequate).

After the above equations are solved, the following quantity is calculated:

$$S_i''' = \frac{S''(x_{i+1}) - S''(x_i)}{x_{i+1} - x_i} \quad , \quad i = 1, 5 \quad (33)$$

Card 2 does the following for j = 1 to 6

1. Finds i such that $x_i \leq t_j < x_{i+1}$
2. Solves the following equations:

$$S''(t_j) = S''(x_i) + (t_j - x_i)S_i''' \quad (34)$$

$$S(t_j, x_i, x_{i+1}) = 1/6 \ [S''(x_i) + S''(x_{i+1}) + S''(t_j)] \quad (35)$$

$$S(t_j) = y_i + (t_j - x_i) \frac{(y_{i+1} - y_i)}{(x_{i+1} - x_i)} + (t_j - x_i)(t_j - x_{i+1})S(t_j, x, x_{i+1}) \quad (36)$$

$$S'(t_j) = (y_{i+1} - y_i) + (2t_j - x_i - x_{i+1})S(t_j, x_1, x_{i+1}) + 1/6 \ (t_j - x_i)(t_j - x_{i+1})S_i''') \quad (37)$$

The spline program can be used to calculate derivatives of the tabular impactor data for six values of particle diameter, d. The values of d chosen must not require extrapolation of the data. If extrapolation is attempted, an error message is printed. The program prompts the user by printing the data that should be read in. Values d should be entered when X is asked

for, f_i should be entered when Y is asked for, tolerance for numerical solution should be entered when TOL is asked for, and values of d for which Pt(d) is to be calculated should be entered when T is asked for. Values d must be input in order of smallest to largest.

Output df(d)/dd is important for calculation of Pt(d) and is labelled S'(T) in the printed output.

Penetration for any particle diameter is given by

$$Pt(d) = \frac{W_o}{W_I}\left[\frac{df_o(d)/dd}{df_I(d)/dd}\right] \tag{38}$$

The use of this program is best demonstrated by an example.

Example 5

Calculate Pt(d) from the following data:

Inlet Data $W_I = 1.305\ g/m^3$		Outlet Data $W_o = 0.00492\ g/m^3$	
d	f	d	f
13.826	0.8731	6.5012	0.9645
7.7369	0.53299	3.638	0.8298
3.2822	0.15228	1.5433	0.5603
1.6815	0.071066	0.7906	0.3688
0.98842	0.035533	0.4648	0.2695
0.79876	0.015228	0.3756	0.1489

Note that d's for calculation of Pt(d) must not exceed 6.5 nor be less than 0.799.

Solution

Choose values of d for calculation of Pt(d). Use 0.8, 1.0, 1.5, 2, 3, and 6. Do inlet first.

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of spline fit card	1	INV 2nd Write	1	
	Enter side 2 of spline fit card	2	INV 2nd Write	2	
2	Clear memory and initialize		2nd Cms E	-1	
3	Input data in order		A	440071	X ?
	from smallest d_{50} to	0.79876	R/S	450071	0.79876
	largest d_{50}	0.015228	R/S	440071	0.015228
					X ?
		0.98842	R/S	450071	0.98842
					Y ?
		0.035533	R/S	440071	0.035533
					X ?
		1.6815	R/S		1.6815
				450071	Y ?
		0.071066	R/S		0.071066
				.440071	X ?
		3.2822	R/S		3.2822
				450071	Y ?
		0.15228	R/S		0.15228
				440071	X ?
		7.7369	R/S		7.7369
				450071	Y ?
		0.53299	R/S		0.53299
				440071	X ?
		13.826	R/S		13.826
				450071	Y ?
		0.8731	R/S		0.8731
4	Enter tolerance for numerical solution	0.0001	R/S	37322771	TOL? 0.0001

The calculator will run for about 3 minutes.

Step	Procedure	Enter	Press	Display	Print
				376536	INPUT T's
5	Input d's for calculation of Pt(d)	0.8	R/S		0.8
				376536	INPUT T's
		1.0	R/S		1.
				376536	INPUT T's
		1.5	R/S		1.5
				376536	INPUT T's
		2.0	R/S		2.
				376536	INPUT T's
		3.0	R/S		3.
				376536	INPUT T's
		6.0	R/S		6.
				300000000	READ CARD 2
6	Read Card 2		CLR	1	
			CLR	2	
7	Calculate		A		See Figure 8 for printer output
	Calculator will run for about 10 seconds and then print.				
8	Record results on magnetic card	3	2nd Write	3	
9	Repeat for outlet				
	Read Card 1 side 1	1	CLR	1	
	Read Card 1 side 2	2	CLR	2	
10	Clear memory and initialize		2nd Cms	-1	
			E		
11	Enter data		A		X ?
		0.3756	R/S		0.3756
					Y ?
		0.1489	R/S		0.1489
					X ?
		0.4648	R/S		0.4648
					Y ?
		0.2695	R/S		0.2695
					X ?

Step	Procedure	Enter	Press	Display	Print
		0.7906	R/S		0.7906
					Y ?
		0.3688	R/S		0.3688
					X ?
		1.5433	R/S		1.5433
					Y ?
		0.5603	R/S		0.5603
					X ?
		3.638	R/S		3.638
					Y ?
		0.8298	R/S		0.8298
					X ?
		6.5012	R/S		6.5012
					Y ?
		0.9645	R/S		0.9645
				376536	TOL ?
	Enter tolerance for numerical solution	0.0001	R/S		0.0001
				376536	INPUT T's
		0.8			0.8
				376536	INPUT T's
		1.0			1.
				376536	INPUT T's
		1.5			1.5
				376536	INPUT T's
		2.0			2.
				376536	INPUT T's
		3.0			3.
				376536	INPUT T's
		6.0			6.
12	Read Card 2 side 1	1	CLR	300000000	READ CARD 2
	Card 2 side 2	2	CLR		
13	Calculate		A		See Figure 8 for printer output

Step	Procedure	Enter	Press	Display	Print
14	Record data on magnetic card	3	2nd Write	3	
15	Read Pt(d) Program Card side 1		CLR	1	
	side 2		CLR	2	
16	Calculate		A		
17	Read inlet card		CLR	3	READ INLET DATA
18	Read outlet card		CLR	3	READ OUTLET DATA
				2431710000	MASS IN ?
19	Enter inlet mass concentration	1.305	R/S		0.1305
				3241377100	MASS OUT ?
20	Enter outlet mass concentration	0.00492	R/S		0.000492
					D =
					0.8
					PT(D) =
					.0002409147
					D =
					1.
					PT(D) =
					.0081617673
					.
					.
					.
					D =
					6
					PT(D) =
					.0021486703
					OVERALL PT =
					.0037701149
				17311600	END

Printer output for this example is shown in Figure 8.

```
      X ?
 0.79876
      Y ?
0.015228
      X ?
 0.98842
      Y ?
0.035533
      X ?
  1.6815
      Y ?
0.071066
      X ?
  3.2822
      Y ?
 0.15228
      X ?
  7.7369
      Y ?
 0.53299
      X ?
  13.826
      Y ?
 0.8731
     TOL?
  0.0001
INPUT  T'S
        0.8
INPUT  T'S
          1.
INPUT  T'S
        1.5
INPUT  T'S
          2.
INPUT  T'S
          3.
INPUT  T'S
          6.
READ CARD 2
```

```
          T =
            0.8
          S''
-.0012980732
        S(TXX1)
-.0333067433
         S(T)
 .0153685362
        S'(T)
 .1133351221

          T =
            1.
          S''
-.1948449069
        S(TXX1)
-.0617716849
         S(T)
 .0366141743
        S'(T)
 0.092230367

          T =
            1.5
          S''
-.0351955372
        S(TXX1)
-.0351634566
         S(T)
 .0650258015
        S'(T)
 .0347202559
```

```
          T =
            2.
          S''
 .0219602419
        S(TXX1)
 .0105782[illegible]03
         S(T)
0.0[illegible]05647
        S'(T)
 .0407126188

          T =
            3.
          S''
 .0194580689
        S(TXX1)
 .0101612014
         S(T)
 .1341813579
        S'(T)
 .0614217742

          T =
            6.
          S''
-.0002447947
        S(TXX1)
 .0010203107
         S(T)
 .3797336807
        S'(T)
 .0919626106

         END
```

Figure 8. Printer Output for Example 5 - Use of TI-59 Program to Calculate Penetration as a Function of Particle Diameter

```
 X ?
0.3756
 Y ?
0.1489
 X ?
0.4648
 Y ?
0.2695
 X ?
0.7906
 Y ?
0.3688
 X ?
1.5433
 Y ?
0.5603
 X ?
3.638
 Y ?
0.8298
 X ?
6.5012
 Y ?
0.9645
TOL?
0.0001
INPUT  T'S
       0.8
INPUT  T'S
       1.
INPUT  T'S
       1.5
INPUT  T'S
       2.
INPUT  T'S
       3.
INPUT  T'S
       6.
READ CARD 2

          T =
            0.8
         S''
 1.156694357
      S(TXX1)
 0.339892683
         S(T)
 .3688166869
        S'(T)
 .0072403722

          T =
            1.
         S''
 .7667973758
      S(TXX1)
 .2749098528
         S(T)
 .3907993352
        S'(T)
 .1995895455

          T =
            1.5
         S''
-.2079450781
      S(TXX1)
 .1124527771
         S(T)
 .5458295111
        S'(T)
 .3393026199

          T =
            2.
         S''
-.2259175925
      S(TXX1)
-.0843164391
         S(T)
 .6821331141
        S'(T)
 .2101228815

          T =
            3.
         S''
-.0804387615
      S(TXX1)
-.0600699672
         S(T)
 .8035436712
        S'(T)
 .0569447045

          T =
            6.
         S''
 .0021665334
      S(TXX1)
 .0024238777
         S(T)
 .9380514439
        S'(T)
 .0524085076

       END
```

Figure 8.(Cont'd)

```
READ INLET DATA
READ OUTLET DATA
MASS IN?
       0.1305
MASS OUT?
     0.000492
          D =
            0.8
PT(D) =
 .0002408524
          D =
              1.
PT(D) =
 .0081586527
          D =
            1.5
PT(D) =
 .0368433309
          D =
              2.
PT(D) =
 .0194580314
          D =
              3.
PT(D) =
 0.003495309
          D =
              6.
PT(D) =
 .0021485482
OVERALL PT =
 .0037701149
        END
```

Figure 8.(Cont'd)

Comparison of Graded Efficiency Calculated from Curve Fit and Spline Fit

"How well does the calculated graded penetration represent the actual graded penetration?" is not a trivial question. It is as nearly impossible to answer.

The actual graded penetration for a real particulate control device is unknown. However, we can create synthetic data from mathematical models and compare data reduction results with the synthetic data. We can also compare results of various methods of calculating the graded penetration with each other when real data are available. Both types of comparisons are made in this section.

The graded penetration calculated using the spline fit, the log-normal, and a quadratic log-normal fit methods are compared in Table 4. It appears that the curve fit methods give good results when the r^2 product is greater than 0.985. This indicates that other types of distribution (such as the upper limit distribution and the Weibull distribution) could be useful. The fits for these distributions could be done by an SR-52 calculator and thus extend the useful range of the SR-52 program set.

The curve fit methods may have an advantage over the spline fit in that statistical information on goodness of fit and confidence limits of fit can be calculated for the curve fit. Such statistical information is not available from the spline fit. Also, curve fits smooth the data; spline fits do not.

Synthetic data were created with the aid of a mathematical model for electrostatic precipitation. "Perfect" impactors were used to sample the inlet particle size distribution fed into the model and the outlet particle size distribution generated by the model. The TI-59 programs were used to reduce the impactor data and calculate the graded penetration. The results of these calculations are summarized in Table 5.

Table 4. COMPARISON OF GRADED PENETRATION CALCULATED USING LINEAR LOG-NORMAL FIT, QUADRATIC LOG-NORMAL FIT AND SPLINE FIT ON ACTUAL IMPACTOR DATA

	Case 1			Case 2			Case 3		
d, μmA	$Pt(d)_{LN}$	$Pt(d)_{LH}^2$	$Pt(d)_s$	$Pt(d)_{LN}$	$Pt(d)_{LN}^2$	$Pt(d)_s$	$Pt(d)_{LN}$	$Pt(d)_{LN}^2$	$Pt(d)_s$
0.87	0.25	0.052	0.0029	0.055	0.048	0.016	0.016	0.075	0.029
1.24	0.18	0.028	0.023	0.023	0.029	0.028	0.029	0.031	0.035
1.78	0.10	0.015	0.028	0.0090	0.016	0.015	0.0099	0.014	0.015
2.53	0.069	0.0070	0.0080	0.0050	0.0081	0.0077	0.0059	0.0070	0.0070
3.62	0.050	0.0030	0.0018	0.0025	0.0038	0.0040	0.0030	0.0038	0.0032
5.16	0.037	0.0012	0.0021	0.0015	0.0016	0.0021	0.0019	0.0021	0.0022
$r_{in}^2 X\ r_{out}^2$	= 0.94 linear log-normal			$r_{in}^2 X\ r_{out}^2$	= 0.97 linear log-normal		$r_{in}^2\ X\ r_{out}^2$	= 0.985 linear log-normal	
	= 0.986 quadratic log-normal				= 0.994 quadratic log-normal			= 0.995 quadratic log-normal	

Table 5. COMPARISON OF GRADED PENETRATION CALCULATED WITH SPLINE AND LOG-NORMAL FITS WITH ACTUAL GRADED PENETRATIONS FROM ESP MODEL

d	$Pt(d)_M$	$Pt(d)_S$	Δ/M
		Case 1	
0.45	0.28	0.27	0.036
0.70	0.26	0.25	0.038
1.0	0.22	0.20	0.091
1.5	0.16	0.14	0.125
2.5	0.094	0.071	0.24
4.0	0.049	0.040	0.18
		Case 2	
0.45	0.28	0.28	0.0
0.70	0.27	0.25	0.074
1.0	0.23	0.21	0.087
1.5	0.17	0.15	0.12
2.5	0.10	0.082	0.18
4.0	0.060	0.052	0.13
		Case 3	
0.45	0.040	0.040	0.0
0.70	0.035	0.033	0.057
1.0	0.026	0.022	0.15
1.5	0.015	0.012	0.20
2.5	0.0075	0.0052	0.31
4.0	0.0021	0.00086	0.59

$Pt(d)_m$ - Pt(d) from ESP Model
$Pt(d)_S$ - Pt(d) from spline fit
Δ_S/M - $(Pt(d)_M - Pt(d)_S)/Pt(d)_M$

The results shown in Table 5 indicate that the graded penetrations calculated from the spline fit are generally in fair agreement with the "real" graded penetrations. However, in some cases, especially when the penetrations are low, the disagreement between the calculated graded penetration and the "real" graded penetration is substantial. Work to determine ways to improve the agreement between the calculated and "real" graded penetrations and to better define the uncertainty in the calculated graded penetrations is underway and will be reported.

Lawless[4] has suggested that the cumulative size distribution data be transformed into log-normal space before the spline fit calculations are performed. Such a transformation will improve the agreement between measured and real graded penetration.

The log-normal values f_i are available in the memory of the TI-59 if one desires to perform the spline fit calculations in log-normal space. The log-normal transforms of the f_i are stored in registers 30 to 35 (transformed f_i is in R_{30}, etc.) and may be recovered by pressing 30 INV 2nd List. Value ln d_i is entered when X is asked for and the corresponding value of transformed f_i is entered when Y is asked for.

The penetration program must be modified to calculate Pt(d) from

$$Pt(d_i) = \frac{W_o \quad \{\exp [- S(d_i)^2/2] \quad X \quad S'(d_i)\} \quad \text{out}}{W_I \quad \{\exp [- S(d_i)^2/2] \quad X \quad S'(d_i)\} \quad \text{in}} \qquad (39)$$

where $S(d_i)$ and $S'(d_i)$ are the output from the spline fit program for d = d_i.

Recommendations for Running Impactors

No matter what method of data reduction is used, the number of points available for calculation of the graded penetration is limited by the number of impactor stages. Also, the values of d for which Pt(d)

can be calculated are limited by the range of the impactor stage d_{50}'s (extrapolation is prohibited). Data points cannot be created by the data reduction technique.

The above points lead to the following recommendations on obtaining impactor data:

1) Six or seven stages covering the range $0.5 \leq d_{A50} \leq 15$ μmA are probably adequate for most purposes.

2) The particle diameter ranges covered by the inlet and outlet impactors are the same or as close to the same as possible. Otherwise data points are lost.

3) Stages d_{A50} for the inlet and outlet impactors should be as close to each other as possible.

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4. Lawless, Phil A., "Analysis of Cascade Impactor Data for Calculating Particle Penetration", Research Triangle Institute, EPA-600/7-78-189, September 1978.

APPENDIX A

USER INSTRUCTIONS AND PROGRAM LISTING FOR SR-52 DATA REDUCTION PROGRAMS

GENERAL

The data reduction programs are contained on six cards which are used in order: Cards 1, 2, 3, 4, and 5 for inlet; Cards 1, 2, 3, 4 and 5 for outlet; and Card 6 for combined inlet and outlet results. The programs use the PC-100A printer.

USER INSTRUCTIONS FOR SR-52 DATA REDUCTION PACKAGE

Step	Procedure	Enter	Press	Display	Print
1	Read sides A and B of Card 1				
2	Check to see if card read properly		RCL 92	Constant for 1st stage	
3	Enter T	T°C or	A	T°C	
		T°F	2nd A'	T°C	
4	Enter Q	Q l/min or	B	Q l/min	
		cfm	2nd B	Q l/min	
5	Initialize		E	1.0000	
6	Reset		2nd rst	1.0000	
7	Calculate d_{A50i}		D	0.0000	
8	Read sides A and B of Card 2				
9	Initialize		E	0.0000	
10	Enter M_i	M_1	A	1.0000	M_1
		M_2	A	2.0000	M_2
		.		.	.
		.		.	.
		.		.	.
		M_{filter}	A	7.0000	M_8

Note: For the MRI and University of Washington impactors, M_1 = the sum of the mass collected on the first two stages. M_1 and M_2 must be added before the data are entered.

11	Read side A of Card 3			
12	Initialize	E	0.0000	
13	Print M_T, $f_i d_{A50i}$		f	M_T
				d_{A501}
				f_1
				.
				.
				.
				d_{A506}

Step	Procedure	Enter	Press	Display	Print
					f_6
14	Read Card 4 sides A and B				
15	Initialize		E	8.0000	
16	Transform f_i		A		
17	Read Card 5 sides A and B				
18	Initialize		E	0.0000	
19	Calculate log-normal parameters		A	J	A B r^2 d_g σ
20	Read Card 6 sides A and B			2nd rst INV READ INV READ	
21	Enter W_I	W_I	A		0.10000
22	Enter W_o	W_o	2nd A'		W_o
23	Enter σ_I	σ_I	B		ln σ_I
24	Enter σ_o	σ_o	2nd B'		ln σ_o
25	Enter d_{gI}	d_{gI}	C		ln d_{gI}
26	Enter d_{go}	d_{go}	2nd C'		ln d_{go}
27	Calculate Pt(D)		D		. Pt(d) 1-Pt(d) 0.1 . . . Pt(d) 1-Pt(d)
				9999.00000	20.0

```
000   46 LBL
001   19   D'
002   01    1
003   44 SUM
004   00    0
005   00    0
006   36 IND
007   43 RCL
008   00    0
009   00    0
010   56 RTN
011   46 LBL
012   10   E'
013   36 IND
014   42 STO
015   01    1
016   09    9
017   01    1
018   44 SUM
019   01    1
020   09    9
021   56 RTN
022   46 LBL
023   18   C'
024   53    (
025   01    1
026   93    .
027   06    6
028   08    8
029   52   EE
030   94   +/-
031   04    4
032   85    +
033   53    (
034   09    9
035   55    ÷
036   05    5
037   65    ×
038   43 RCL
039   00    0
040   08    8
041   85    +
042   03    3
043   02    2
044   54    )
045   65    ×
046   02    2
047   93    .
048   02    2
049   09    9
050   02    2
051   52   EE
052   94   +/-
053   07    7
054   54    )
055   56 RTN
056   46 LBL
057   13    C
058   81 HLT
059   42 STO
060   00    0
061   00    0
062   46 LBL
063   87    1'
064   19    D'
065   98 PRT
066   43 RCL
067   00    0
068   00    0
069   98 PRT
070   75    -
071   07    7
072   95    =
073   90 IFZ
074   88    2'
075   41 GTO
076   87    1'
077   46 LBL
078   88    2'
079   81 HLT
080   46 LBL
081   14    D
082   19    D'
083   65    ×
084   18    C'
085   55    ÷
086   43 RCL
087   00    0
088   09    9
089   65    ×
090   01    1
091   52   EE
092   08    8
093   95    =
094   30    TX
095   10   E'
096   43 RCL
097   01    1
098   09    9
099   75    -
```

Impactor Data Reduction Program Listing Card 1

```
100   32   XT
101   95    =
102   90  IFZ
103   13    C
104   41  GTO
105   14    D
106   46  LBL
107   11    A
108   42  STO
109   00    0
110   08    8
111   81  HLT
112   46  LBL
113   12    B
114   42  STO
115   00    0
116   09    9
117   81  HLT
118   46  LBL
119   16    A'
120   75    -
121   03    3
122   03    3
123   95    =
124   65    ×
125   05    5
126   55    ÷
127   09    9
128   95    =
129   11    A
130   46  LBL
131   17    B'
132   55    ÷
133   93    .
134   00    0
135   03    3
136   05    5
137   03    3
138   02    2
139   95    =
140   12    B
141   46  LBL
142   15    E
143   09    9
144   01    1
145   42  STO
146   00    0
147   00    0
148   01    1
149   42  STO
150   01    1
151   09    9
152   32   XT
153   82   EE
154   87  FIX
155   04    4
156   81  HLT
```

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Impactor Data Reduction Program Listing Card 1 (Cont'd)

```
000   46  LBL
001   11   A
002   98  PRT
003   36  IND
004   42  STO
005   00   0
006   00   0
007   44  SUM
008   01   1
009   09   9
010   01   1
011   44  SUM
012   00   0
013   00   0
014   43  RCL
015   00   0
016   00   0
017   75   -
018   08   8
019   09   9
020   95   =
021   81  HLT
022   46  LBL
023   15   E
024   01   1
025   03   3
026   42  STO
027   00   0
028   07   7
029   08   8
030   09   9
031   43  STO
032   00   0
033   00   0
034   00   0
035   42  STO
036   01   1
037   06   6
038   42  STO
039   01   1
040   07   7
041   42  STO
042   01   1
043   08   8
044   42  STO
045   01   1
046   09   9
047   81  HLT
048   46  LBL
049   12   B
050   43  RCL
051   00   0
052   00   0
053   75   -
054   01   1
055   95   =
056   42  STO
057   01   1
058   06   6
059   75   -
060   01   1
061   95   =
062   42  STO
063   01   1
064   08   8
065   46  LBL
066   88   2'
067   36  IND
068   43  RCL
069   01   1
070   06   6
071   44  SUM
072   01   1
073   07   7
074   01   1
075   23  INV
076   44  SUM
077   01   1
078   06   6
079   23  INV
080   44  SUM
```

Impactor Data Reduction Program Listing Card 2

```
081   01   1
082   08   8
083   43 RCL
084   01   1
085   07   7
086   55   ÷
087   43 RCL
088   01   1
089   09   9
090   95   =
091   36 IND
092   42 STO
093   00   0
094   07   7
095   01   1
096   22 INV
097   44 SUM
098   00   0
099   07   7
100   43 RCL
101   00   0
102   07   7
103   75   -
104   07   7
105   95   =
106   90 IFI
107   77   4'
108   41 GTO
109   88   2'
110   46 LBL
111   77   4'
112   91 HLT
```

Impactor Data Reduction Progam Listing Card 2 (Cont'd)

```
000   46 LBL
001   11  A
002   99 PAP
003   43 RCL
004   01  1
005   09  9
006   22 INV
007   52 EE
008   98 PRT
009   12  B
010   81 HLT
011   46 LBL
012   12  B
013   99 PAP
014   01  1
015   42 STO
016   00  0
017   00  0
018   08  8
019   42 STO
020   01  1
021   09  9
022   46 LBL
023   87  1'
024   36 IND
025   43 RCL
026   00  0
027   00  0
028   98 PRT
029   36 IND
030   43 RCL
031   01  1
032   09  9
033   98 PRT
034   99 PAP
035   01  1
036   44 SUM
037   00  0
038   00  0
039   44 SUM
040   01  1
041   09  9
042   43 RCL
043   00  0
044   00  0
045   75  -
046   07  7
047   95  =
048   22 INV
049   90 IFZ
050   87  1'
051   56 RTN
```

Impactor Data Reduction Program Card 3

```
000   46  LBL
001   11    A
002   93    .
003   05    5
004   75    -
005   36  IND
006   43  RCL
007   00    0
008   00    0
009   22  INV
010   50  STF
011   01    1
012   42  STO
013   01    1
014   09    9
015   95    =
016   22  INV
017   80  IF+
018   87    1'
019   46  LBL
020   88    2'
021   12    B
022   80  IFF
023   01    1
024   77    4'
025   94  +/-
026   46  LBL
027   77    4'
028   36  IND
029   42  STO
030   00    0
031   00    0
032   43  RCL
033   00    0
034   00    0
035   75    -
036   01    1
037   03    3
038   95    =
039   80  IF□
040   78    8'
041   01    1
042   44  SUM
043   00    0
044   00    0
045   41  GTO
046   11    A
047   46  LBL
048   79    9'
049   31  HLT
```

```
050   46  LBL
051   15    E
052   08    8
053   42  STO
054   00    0
055   00    0
056   81  HLT
057   46  LBL
058   12    B
059   43  RCL
060   01    1
061   09    9
062   40    X²
063   20  1/X
064   23  LNX
065   30    ΓX
066   53    (
067   42  STO
068   01    1
069   08    8
070   75    -
071   53    (
072   53    (
073   43  RCL
074   09    9
075   02    2
076   85    +
077   15    E'
078   65    ×
079   43  RCL
080   03    3
081   02    2
082   85    +
083   16    A'
084   40    X²
085   65    ×
086   43  RCL
087   04    4
088   04    4
089   54    )
090   55    ÷
091   53    (
092   01    1
093   85    +
094   16    A'
095   65    ×
096   43  RCL
097   05    5
098   05    5
099   54    )
```

Impactor Data Reduction Program Listing Card 4

```
100   16   A'
101   40   X²
102   65   ×
103   43 RCL
104   09   9
105   06   6
106   85   +
107   16   A'
108   45 Y×
109   03   3
110   65   ×
111   43 RCL
112   09   9
113   07   7
114   54   )
115   54   )
116   54   )
117   56 RTN
118   46 LBL
119   87   1'
120   50 STF
121   01   1
122   53   (
123   43 RCL
124   01   1
125   09   9
126   94 +/-
127   85   +
128   01   1
129   54   )
130   42 STO
131   01   1
132   09   9
133   41 GTO
134   88   2'
135   46 LBL
136   16   A'
137   43 RCL
138   01   1
139   08   8
140   56 RTN
```

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Impactor Data Reduction Program Listing Card 4 (Cont'd)

```
046   44 SUM
047   00  0
048   00  0
049   44 SUM
050   01  1
051   09  9
052   11  A
053   46 LBL
054   88  2'
055   43 RCL
056   01  1
057   06  6
058   75  -
059   53  (
060   43 RCL
061   01  1
062   05  5
063   55  ÷
064   06  6
065   54  )
066   65  ×
067   43 RCL
068   01  1
069   04  4
070   95  =
071   55  ÷
072   53  (
073   43 RCL
074   01  1
075   08  8
076   75  -
077   53  (
078   43 RCL
079   01  1
080   04  4
081   55  ÷
082   06  6
083   54  )
084   65  ×
085   43 RCL
086   01  1
087   04  4
088   54  )
089   95  =
090   98 PRT
```

```
000   46 LBL
001   11  A
002   36 IND
003   43 RCL
004   00  0
005   00  0
006   23 LNX
007   42 STO
008   00  0
009   07  7
010   44 SUM
011   01  1
012   04  4
013   40  X²
014   44 SUM
015   01  1
016   08  8
017   36 IND
018   43 RCL
019   01  1
020   09  9
021   49 PRD
022   00  0
023   07  7
024   44 SUM
025   01  1
026   05  5
027   40  X²
028   44 SUM
029   01  1
030   07  7
031   43 RCL
032   00  0
033   07  7
034   44 SUM
035   01  1
036   06  6
037   43 RCL
038   00  0
039   00  0
040   75  -
041   06  6
042   95  =
043   90 IFZ
044   88  2'
045   01  1
```

Impactor Data Reduction Program Listing Card 5

```
091   42 STO
092   00   0
093   00   0
094   65   ×
095   43 RCL
096   01   1
097   04   4
098   55   ÷
099   06   6
100   94 +/-
101   85   +
102   53   (
103   43 RCL
104   01   1
105   05   5
106   55   ÷
107   06   6
108   54   )
109   95   =
110   98 PRT
111   42 STO
112   01   1
113   09   9
114   53   (
115   43 RCL
116   01   1
117   06   6
118   75   -
119   53   (
120   43 RCL
121   01   1
122   05   5
123   55   ÷
124   06   6
125   54   )
126   65   ×
127   43 RCL
128   01   1
129   04   4
130   95   =
131   40   x²
132   54   )
133   53   (
134   53   (
135   43 RCL
```

```
136   01   1
137   08   8
138   75   -
139   53   (
140   43 RCL
141   01   1
142   04   4
143   55   ÷
144   06   6
145   54   )
146   65   ×
147   43 RCL
148   01   1
149   04   4
150   54   )
151   65   ×
152   53   (
153   43 RCL
154   01   1
155   07   7
156   75   -
157   43 RCL
158   01   1
159   05   5
160   65   ×
161   53   (
162   43 RCL
163   01   1
164   05   5
165   55   ÷
166   06   6
167   54   )
168   54   )
169   95   =
170   98 PRT
171   43 RCL
172   01   1
173   09   9
174   55   ÷
175   43 RCL
176   00   0
177   00   0
178   94 +/-
179   95   =
180   22 INV
```

Impactor Data Reduction Program Listing Card 5 (Cont'd)

```
181   23  LNX
182   98  PRT
183   43  RCL
184   00   0
185   00   0
186   20  1/X
187   22  INV
188   23  LNX
189   98  PRT
190   81  HLT
191   46  LBL
192   15   E
193   01   1
194   42  STO
195   00   0
196   00   0
197   08   8
198   42  STO
199   01   1
200   09   9
201   00   0
202   42  STO
203   00   0
204   07   7
205   42  STO
206   01   1
207   04   4
208   42  STO
209   01   1
210   05   5
211   42  STO
212   01   1
213   06   6
214   42  STO
215   01   1
216   07   7
217   42  STO
218   01   1
219   08   8
220   56  RTN
```

Impactor Data Reduction Program Listing Card 5 (Cont'd)

```
LOG NORMAL PT
          000   46  LBL
          001   11   A
          002   42  STO
          003   00   0
          004   01   1
          005   22  INV
          006   50  STF
          007   01   1
          008   93   .
          009   01   1
          010   42  STO
          011   00   0
          012   00   0
          013   81  HLT
          014   46  LBL
          015   16   A'
          016   42  STO
          017   00   0
          018   02   2
          019   81  HLT
          020   46  LBL
          021   12   B
          022   23  LNX
          023   42  STO
          024   00   0
          025   03   3
          026   81  HLT
          027   46  LBL
          028   17   B'
          029   23  LNX
          030   42  STO
          031   00   0
          032   04   4
          033   81  HLT
          034   46  LBL
          035   13   C
          036   23  LNX
          037   42  STO
          038   00   0
          039   05   5
          040   81  HLT
          041   46  LBL
          042   18   C'
          043   23  LNX
          044   42  STO
          045   00   0
          046   06   6
          047   81  HLT
          048   46  LBL
          049   15   E
          050   53   (
          051   53   (
          052   43  RCL
          053   00   0
          054   00   0
          055   23  LNX
          056   75   -
          057   43  RCL
          058   00   0
          059   05   5
          060   54   )
          061   55   ÷
          062   43  RCL
          063   00   0
          064   03   3
          065   54   )
          066   40   X²
          067   56  RTN
          068   56  RTN
          069   46  LBL
          070   10   E'
          071   53   (
          072   53   (
          073   43  RCL
          074   00   0
          075   00   0
          076   23  LNX
          077   75   -
          078   43  RCL
          079   00   0
          080   06   6
          081   54   )
          082   55   ÷
          083   43  RCL
          084   00   0
          085   04   4
          086   54   )
          087   40   X²
          088   56  RTN
          089   46  LBL
          090   14   D
          091   43  RCL
          092   00   0
          093   02   2
          094   55   ÷
          095   43  RCL
          096   00   0
          097   01   1
          098   65   ×
          099   43  RCL
          100   00   0
```

Log-normal Penetration Program Listing

```
101   03   3
102   55   ÷
103   43  RCL
104   00   0
105   04   4
106   65   ×
107   53   (
108   53   (
109   15   E
110   75   -
111   10   E'
112   54   )
113   55   ÷
114   02   2
115   54   )
116   22  INV
117   23  LNX
118   95   =
119   57  FIX
120   05   5
121   98  PRT
122   75   -
123   01   1
124   95   =
125   94  +/-
126   98  PRT
127   43  RCL
128   00   0
129   00   0
130   98  PRT
131   99  PAP
132   75   -
133   01   1
134   95   =
135   90  IFZ
136   87   1'
137   60  IFF
138   01   1
139   87   1'
140   93   .
141   01   1
142   44  SUM
143   00   0
144   00   0
145   41  GTO
146   14   D
147   46  LBL
148   87   1'
149   50  STF
150   01   1
```

```
151   43  RCL
152   00   0
153   00   0
154   75   -
155   02   2
156   00   0
157   95   =
158   90  IFZ
159   88   2'
160   01   1
161   44  SUM
162   00   0
163   00   0
164   41  GTO
165   14   D
166   46  LBL
167   88   2'
168   09   9
169   09   9
170   09   9
171   09   9
172   09   9
173   09   9
174   81  HLT
```

Log-normal Penetration Program Listing (cont'd)

APPENDIX B

USER INSTRUCTIONS AND PROGRAM LISTING FOR TI-59
IMPACTOR DATA REDUCTION PACKAGE

INTRODUCTION

This program calculates and prints cascade impactor aerodynamic cut diameters, d_{A50}, cumulative fraction less than and the least-squares log-normal fit to the data. Input requirements are impactor temperature, °C, impactor flow rate, l/m, and mass collected by each impactor stage. The program uses the PC-100A printer and the Master Library Module.

Nomenclature, in order used by program:

T	=	impactor temperature, °C
P	=	impactor pressure, cm Hg
Q	=	impactor flow rate, l/m
Mass	=	mass of particulate collected per stage
D50	=	aerodynamic impactor cut diameter, μmA
FI	=	cumulative fraction less than
A	=	least-squares fit constant, A, in y = A + Bx
B	=	least-squares fit constant, B, in y = A + Bx
R**	=	correlation coefficient, r^2
DG	=	Aerodynamic mass mean particle diameter of log-normal size distribution, μmA
SIGMA	=	geometric standard deviation of log-normal size distribution

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of card		Clr	1	
	Read side 2 of Card		Clr	2	
	Read card with stage constants		Clr	3	

Step	Procedure	Enter	Press	Display	Print
2	Start calculation		A	370064	T =
	Enter temperature °C	T°C	R/S		
	Enter pressure cm Hg	P cm Hg	R/S	330064	P =
	Enter flow rate	l/m	R/S	340064	Q =
				3013363600	MASS
	Enter mass collected	M	R/S		
	per stage				.
					.
					.
				3013363600	MASS
		M_n	R/S		
					D50
					F_I
					.
					.
					FI
					A
					B
					R**2
					DG
					SIGMA
					σ

```
000   76 LBL
001   11  A
002   00  0
003   42 STO
004   58  58
005   69 OP
006   00  00
007   03  3
008   07  7
009   00  0
010   00  0
011   06  6
012   04  4
013   69 OP
014   02  02
015   69 OP
016   05  05
017   91 R/S
018   42 STO
019   01  01
020   42 STO
021   59  59
022   99 PRT
023   03  3
024   03  3
025   00  0
026   00  0
027   06  6
028   04  4
029   69 OP
030   02  02
031   69 OP
032   05  05
033   91 R/S
034   42 STO
035   36  36
036   99 PRT
037   69 OP
038   00  00
039   03  3
040   04  4
041   00  0
042   00  0
043   06  6
044   04  4
045   69 OP
046   02  02
047   69 OP
048   05  05
049   91 R/S
050   99 PRT
051   42 STO
052   02  02
053   00  0
054   42 STO
055   53  53
056   42 STO
057   58  58
058   07  7
059   42 STO
060   00  00
061   01  1
062   07  7
063   42 STO
064   54  54
065   76 LBL
066   87 IFF
067   69 OP
068   00  00
069   03  3
070   00  0
071   01  1
072   03  3
073   03  3
074   06  6
075   03  3
076   06  6
077   00  0
078   00  0
079   69 OP
080   02  02
081   69 OP
082   05  05
083   91 R/S
084   99 PRT
085   72 ST*
086   54  54
087   44 SUM
088   53  53
089   01  1
090   44 SUM
091   54  54
092   97 DSZ
093   00  00
094   87 IFF
095   07  7
096   42 STO
097   00  00
098   00  0
099   04  4
100   00  0
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1

```
101   42 STO
102   54   54
103   01    1
104   00    0
105   42 STO
106   55   55
107   76 LBL
108   88 DMS
109   73 RC*
110   54   54
111   55    ÷
112   43 RCL
113   02   02
114   65    ×
115   16 A'
116   65    ×
117   01    1
118   52 EE
119   08    8
120   95    =
121   34 fX
122   72 ST*
123   55   55
124   01    1
125   44 SUM
126   54   54
127   44 SUM
128   55   55
129   97 DSZ
130   00   00
131   88 DMS
132   03    3
133   05    5
134   42 STO
135   55   55
136   06    6
137   42 STO
138   00   00
139   02    2
140   03    3
141   42 STO
142   54   54
143   03    3
144   05    5
145   42 STO
146   57   57
147   02    2
148   09    9
149   42 STO
150   52   56
151   76 LBL
152   89    π
153   73 RC*
154   54   54
155   44 SUM
156   58   58
157   43 RCL
158   58   58
159   55    ÷
160   43 RCL
161   53   53
162   95    =
163   72 ST*
164   56   56
165   12    B
166   72 ST*
167   57   57
168   01    1
169   94 +/-
170   44 SUM
171   54   54
172   44 SUM
173   56   56
174   44 SUM
175   57   57
176   44 SUM
177   55   55
178   25 CLR
179   97 DSZ
180   00   00
181   89    π
182   36 PGM
183   01   01
184   71 SBR
185   25 CLR
186   01    1
187   06    6
188   42 STO
189   54   54
190   03    3
191   05    5
192   42 STO
193   55   55
194   06    6
195   42 STO
196   00   00
197   76 LBL
198   77   GE
199   73 RC*
200   54   54
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

```
201   23 LNX
202   32 X:T
203   73 RC*
204   55   55
205   78 Σ+
206   01   1
207   94 +/-
208   44 SUM
209   54   54
210   44 SUM
211   55   55
212   25 CLR
213   97 DSZ
214   00   00
215   77   GE
216   01   1
217   06   6
218   42 STO
219   54   54
220   02   2
221   09   9
222   42 STO
223   55   55
224   06   6
225   42 STO
226   00   00
227   76 LBL
228   78 Σ+
229   69 OP
230   00   00
231   01   1
232   06   6
233   00   0
234   06   6
235   00   0
236   01   1
237   69 OP
238   01   01
239   69 OP
240   05   05
241   73 RC*
242   54   54
243   99 PRT
244   02   2
245   01   1
246   02   2
247   04   4
248   00   0
249   00   0
250   69 OP
251   01   01
252   69 OP
253   05   05
254   73 RC*
255   55   55
256   99 PRT
257   01   1
258   94 +/-
259   44 SUM
260   54   54
261   44 SUM
262   55   55
263   25 CLR
264   97 DSZ
265   00   00
266   78 Σ+
267   69 OP
268   00   00
269   01   1
270   03   3
271   69 OP
272   01   01
273   69 OP
274   05   05
275   69 OP
276   12   12
277   99 PRT
278   69 OP
279   00   00
280   01   1
281   04   4
282   69 OP
283   01   01
284   69 OP
285   05   05
286   69 OP
287   12   12
288   32 X:T
289   99 PRT
290   69 OP
291   00   00
292   03   3
293   05   5
294   05   5
295   01   1
296   05   5
297   01   1
298   00   0
299   03   3
300   69 OP
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

```
301   01   01
302   69   OP
303   05   05
304   69   OP
305   13   13
306   33   X²
307   99   PRT
308   69   OP
309   00   00
310   01   1
311   06   6
312   02   2
313   02   2
314   69   OP
315   01   01
316   69   OP
317   05   05
318   69   OP
319   12   12
320   55   ÷
321   32   X:T
322   95   =
323   94   +/-
324   22   INV
325   23   LNX
326   99   PRT
327   69   OP
328   00   00
329   03   3
330   06   6
331   02   2
332   04   4
333   02   2
334   02   2
335   03   3
336   00   0
337   01   1
338   03   3
339   69   OP
340   01   01
341   69   OP
342   05   05
343   69   OP
344   12   12
345   32   X:T
346   35   1/X
347   22   INV
348   23   LNX
349   99   PRT
350   92   RTN
```

```
351   76   LBL
352   16   A'
353   53   (
354   53   (
355   43   RCL
356   01   01
357   65   ×
358   09   9
359   55   ÷
360   05   5
361   85   +
362   03   3
363   02   2
364   54   )
365   65   ×
366   02   2
367   93   .
368   02   2
369   09   9
370   02   2
371   52   EE
372   94   +/-
373   07   7
374   85   +
375   01   1
376   93   .
377   06   6
378   08   8
379   52   EE
380   94   +/-
381   04   4
382   54   )
383   92   RTN
384   76   LBL
385   12   B
386   93   .
387   05   5
388   32   X:T
389   73   RC*
390   56   56
391   42   STO
392   09   09
393   77   GE
394   69   OP
395   86   STF
396   01   01
397   53   (
398   01   1
399   75   -
400   73   RC*
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

```
401  56  56
402  54  )
403  42  STO
404  09  09
405  76  LBL
406  69  DP
407  53  (
408  01  1
409  75  -
410  43  RCL
411  09  09
412  54  )
413  35  1/X
414  33  X²
415  23  LNX
416  34  √X
417  42  STO
418  09  09
419  53  (
420  43  RCL
421  09  09
422  75  -
423  53  (
424  53  (
425  43  RCL
426  47  47
427  85  +
428  43  RCL
429  09  09
430  65  ×
431  43  RCL
432  48  48
433  85  +
434  43  RCL
435  09  09
436  33  X²
437  65  ×
438  43  RCL
439  49  49
440  54  )
441  55  ÷
442  53  (
443  01  1
444  85  +
445  43  RCL
446  09  09
447  65  ×
448  43  RCL
449  50  50
450  85  +
451  43  RCL
452  09  09
453  33  X²
454  65  ×
455  43  RCL
456  51  51
457  85  +
458  43  RCL
459  52  52
460  65  ×
461  43  RCL
462  09  09
463  45  Y^X
464  03  3
465  54  )
466  54  )
467  54  )
468  87  IFF
469  01  01
470  38  SIN
471  92  RTN
472  76  LBL
473  38  SIN
474  22  INV
475  86  STF
476  01  01
477  94  +/-
478  92  RTN
```

Program Listing TI-59 Cascade Impactor Data Reduction--Card 1 (Cont'd)

APPENDIX C

USER INSTRUCTIONS AND PROGRAM LISTING FOR TI-59 PROGRAM TO CONVERT AERODYNAMIC DIAMETER TO PHYSICAL DIAMETER

GENERAL

This program converts aerodynamic diameter to physical diameter. Aerodynamic diameter, d_A, and physical diameter are printed. The program then calculates and prints cumulative fraction less than for each stage, and the log-normal fit to the data. Input requirements are particle density, g/cc. The program uses the PC-100A printer and the Master Library Module.

Nomenclature, in order used by program:

DENSITY	=	particle density, g/cc
DA	=	aerodynamic particle diameter, μmA
DP	=	physical particle diameter, μm
D_{50}	=	physical impactor cut diameter, μm
F_I	=	cumulative fraction less than
A	=	least-squares fit constant, A, in y = A + Bx
B	=	least-squares fit constant, B, in y = A + Bx
R**	=	correlation coefficient, r^2
D_G	=	physical mass mean particle diameter of log-normal size distribution, μm
SIGMA	=	geometric standard deviation of log-normal size distribution

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Enter Side 1 of card		CLR	1	
	Enter Side 2 of card		CLR	2	
	Begin calculation		A		DENSITY
	Enter density	ρ	R/S		

Step	Procedure	Enter	Press	Display	Print
					d_A DA
					D DP
					.
					.
					.
					SIGMA
					σ

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```
000   76 LBL
001   14  D
002   73 RC+
003   54  54
004   92 RTN
005   76 LBL
006   13  C
007   53  (
008   01  1
009   85  +
010   02  2
011   65  ×
012   43 RCL
013   42  42
014   55  ÷
015   43 RCL
016   40  40
017   65  ×
018   53  (
019   01  1
020   93  .
021   02  2
022   06  6
023   85  +
024   93  .
025   04  4
026   02  2
027   65  ×
028   53  (
029   93  .
030   08  8
031   07  7
032   65  ×
033   43 RCL
034   40  40
035   55  ÷
036   53  (
037   02  2
038   65  ×
039   43 RCL
040   42  42
041   54  )
042   54  )
043   94 +/-
044   22 INV
045   23 LNX
046   54  )
047   54  )
048   92 RTN
049   76 LBL
050   11  A
051   01  1
052   06  6
053   01  1
054   07  7
055   03  3
056   01  1
057   03  3
058   06  6
059   02  2
060   04  4
061   69 DP
062   00  00
063   69 DP
064   02  02
065   03  3
066   07  7
067   04  4
068   05  5
069   07  7
070   01  1
071   00  0
072   00  0
073   00  0
074   00  0
075   69 DP
076   03  03
077   69 DP
078   05  05
079   91 R/S
080   99 PRT
081   42 STO
082   43  43
083   93  .
084   00  0
085   06  6
086   05  5
087   03  3
088   65  ×
089   07  7
090   06  6
091   55  ÷
092   02  2
093   09  9
094   06  6
095   93  .
096   02  2
097   65  ×
098   53  (
099   43 RCL
100   59  59
```

Program Listing Program to Convert Aerodynamic Diameter to Physical Diameter

```
101   85  +
102   02  2
103   07  7
104   03  3
105   54  )
106   55  ÷
107   43 RCL
108   36  36
109   95  =
110   42 STO
111   42  42
112   01  1
113   01  1
114   42 STO
115   54  54
116   06  6
117   42 STO
118   00  00
119   69 OP
120   00  00
121   93  .
122   00  0
123   00  0
124   01  1
125   32 X:T
126   76 LBL
127   87 IFF
128   98 ADV
129   01  1
130   06  6
131   01  1
132   03  3
133   69 OP
134   04  04
135   73 RC*
136   54  54
137   69 OP
138   06  06
139   55  ÷
140   43 RCL
141   42  42
142   34 ΓX
143   95  =
144   42 STO
145   40  40
146   42 STO
147   41  41
148   76 LBL
149   89 DMS
150   43 RCL
151   41  41
152   42 STO
153   40  40
154   14  D
155   55  ÷
156   53  (
157   13  C
158   65  ×
159   43 RCL
160   43  43
161   54  )
162   34 ΓX
163   95  =
164   42 STO
165   41  41
166   75  -
167   43 RCL
168   40  40
169   95  =
170   50 I×I
171   55  ÷
172   43 RCL
173   40  40
174   95  =
175   77  GE
176   88 DMS
177   01  1
178   06  6
179   03  3
180   03  3
181   69 OP
182   04  04
183   43 RCL
184   41  41
185   69 OP
186   06  06
187   72 ST*
188   54  54
189   01  1
190   44 SUM
191   54  54
192   97 DSZ
193   00  00
194   87 IFF
195   36 PGM
196   01  01
197   71 SBR
198   25 CLR
199   01  1
200   06  6
```

rogram Listing Program to Convert Aerodynamic Diameter to Physical Diameter (Cont'd)

```
201   42 STO
202   54  54
203   03  3
204   05  5
205   42 STO
206   55  55
207   06  6
208   42 STO
209   00  00
210   98 ADV
211   76 LBL
212   77  GE
213   73 RC*
214   54  54
215   23 LNX
216   32 X:T
217   73 RC*
218   55  55
219   78 Σ+
220   01  1
221   94 +/-
222   44 SUM
223   54  54
224   44 SUM
225   55  55
226   25 CLR
227   97 DSZ
228   00  00
229   77  GE
230   01  1
231   06  6
232   42 STO
233   54  54
234   02  2
235   09  9
236   42 STO
237   55  55
238   06  6
239   42 STO
240   00  00
241   76 LBL
242   78 Σ+
243   69 □P
244   00  00
245   00  0
246   01  1
247   06  6
248   00  0
249   06  6
250   00  0
```

```
251   01  1
252   69 □P
253   01  01
254   69 □P
255   05  05
256   73 RC*
257   54  54
258   99 PRT
259   69 □P
260   00  00
261   02  2
262   01  1
263   02  2
264   04  4
265   00  0
266   00  0
267   69 □P
268   01  01
269   69 □P
270   05  05
271   73 RC*
272   55  55
273   99 PRT
274   01  1
275   94 +/-
276   44 SUM
277   54  54
278   44 SUM
279   55  55
280   25 CLR
281   97 DSZ
282   00  00
283   78 Σ+
284   69 □P
285   00  00
286   01  1
287   03  3
288   69 □P
289   01  01
290   69 □P
291   05  05
292   69 □P
293   12  12
294   99 PRT
295   69 □P
296   00  00
297   01  1
298   04  4
299   69 □P
300   01  01
```

Program Listing Program to Convert Aerodynamic Diameter to Physical Diameter (Cont'd)

```
301  69 □P
302  05  05
303  69 □P
304  12  12
305  32 X↕T
306  99 PRT
307  03  3
308  05  5
309  05  5
310  01  1
311  05  5
312  01  1
313  00  0
314  03  3
315  69 □P
316  01  01
317  69 □P
318  05  05
319  69 □P
320  13  13
321  33 X²
322  99 PRT
323  69 □P
324  00  00
325  01  1
326  06  6
327  02  2
328  02  2
329  69 □P
330  01  01
331  69 □P
332  05  05
333  69 □P
334  12  12
335  55  ÷
336  32 X↕T
337  95  =
338  94 +/-
339  22 INV
340  23 LNX
341  99 PRT
342  03  3
343  06  6
344  02  2
345  04  4
346  02  2
347  02  2
348  03  3
349  00  0
350  01  1
351  03  3
352  69 □P
353  01  01
354  69 □P
355  05  05
356  69 □P
357  12  12
358  32 X↕T
359  35 1/X
360  22 INV
361  23 LNX
362  99 PRT
363  92 RTN
```

Program listing Program to Convert Aerodynamic Diameter to Physical Diameter (Cont'd)

APPENDIX D

USER INSTRUCTIONS AND PROGRAM LISTING FOR PROGRAM
TO ESTIMATE VISCOSITY OF MIXTURES

GENERAL

This program estimates the viscosity of mixtures of gases. The input data requirements are: number of components (10 maximum), and the viscosity, molecular weight and mole fraction of each pure component.

Nomenclature in order used by program:

N = Total number of components
I = Number identifying component for which input data are required
VIS = Viscosity of component number I
MW = Molecular weight of component number I
X = Mole fraction of component number I

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of card		Clr	1	
	Enter side 2 of card		Clr	2	
2	Start calculation		A	3171	N?
	Enter number of components	n	R/S		n
					I = n
				42243671.00	VIS?
3	Enter μ_n	μ_n	R/S		μ_n
				3043710000	MIN?
4	Enter MW_n	MW_n	R/S		MIN_n
				4471.0000	X?

Step	Procedure	Enter	Press	Display	Print
5	Enter X_i	X_i			X_i I = n-1
	Repeat steps 3, 4 and 5 for all components				
				$\mu_{mixture}$	$\mu_{mixture}^{VIS}$

```
000   76 LBL
001   87 IFF
002   12  B
003   43 RCL
004   00  00
005   94 +/-
006   44 SUM
007   50  50
008   44 SUM
009   51  51
010   44 SUM
011   52  52
012   25 CLR
013   73 RC*
014   50  50
015   42 STO
016   40  40
017   73 RC*
018   51  51
019   42 STO
020   41  41
021   73 RC*
022   52  52
023   42 STO
024   42  42
025   00  0
026   42 STO
027   53  53
028   43 RCL
029   00  00
030   32 X:T
031   76 LBL
032   88 DMS
033   12  B
034   43 RCL
035   59  59
036   67  EQ
037   89  π
038   94 +/-
039   44 SUM
040   50  50
041   44 SUM
042   51  51
043   44 SUM
044   52  52
045   25 CLR
046   53  (
047   01  1
048   85  +
049   53  (
050   43 RCL
051   40  40
052   55  ÷
053   73 RC*
054   50  50
055   54  )
056   34 √X
057   65  ×
058   53  (
059   73 RC*
060   51  51
061   55  ÷
062   43 RCL
063   41  41
064   54  )
065   45 Y^x
066   93  .
067   02  2
068   05  5
069   54  )
070   33 X²
071   55  ÷
072   53  (
073   08  8
074   34 √X
075   65  ×
076   53  (
077   01  1
078   85  +
079   43 RCL
080   41  41
081   55  ÷
082   73 RC*
083   51  51
084   54  )
085   34 √X
086   54  )
087   65  ×
088   73 RC*
089   52  52
090   55  ÷
091   43 RCL
092   42  42
093   95  =
094   44 SUM
095   53  53
096   76 LBL
097   89  π
098   12  B
099   97 DSZ
100   59  59
```

Program Listing Viscosity Program

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```
101   88 DMS
102   43 RCL
103   40  40
104   55  ÷
105   53  (
106   43 RCL
107   53  53
108   85  +
109   01  1
110   54  )
111   95  =
112   44 SUM
113   54  54
114   43 RCL
115   58  58
116   42 STO
117   59  59
118   12  B
119   97 DSZ
120   00  00
121   87 IFF
122   13  C
123   91 R/S
124   76 LBL
125   12  B
126   43 RCL
127   58  58
128   85  +
129   01  1
130   95  =
131   42 STO
132   50  50
133   43 RCL
134   58  58
135   85  +
136   01  1
137   01  1
138   95  =
139   42 STO
140   51  51
141   43 RCL
142   58  58
143   85  +
144   02  2
145   01  1
146   95  =
147   42 STO
148   52  52
149   92 RTN
150   76 LBL
151   11  A
152   69 □P
153   00  00
154   03  3
155   01  1
156   07  7
157   01  1
158   69 □P
159   02  02
160   69 □P
161   05  05
162   91 R/S
163   58 FIX
164   04  04
165   99 PRT
166   42 STO
167   58  58
168   42 STO
169   00  00
170   42 STO
171   59  59
172   00  0
173   12  B
174   76 LBL
175   38 SIN
176   12  B
177   98 ADV
178   69 □P
179   00  00
180   02  2
181   04  4
182   06  6
183   04  4
184   69 □P
185   02  02
186   69 □P
187   05  05
188   43 RCL
189   00  00
190   99 PRT
191   94 +/-
192   44 SUM
193   50  50
194   44 SUM
195   51  51
196   44 SUM
197   52  52
198   04  4
199   02  2
200   02  2
```

Program Listing Viscosity Program (Cont'd)

```
201   04   4
202   03   3
203   06   6
204   07   7
205   01   1
206   69 □P
207   02   02
208   69 □P
209   05   05
210   91 R/S
211   99 PRT
212   72 ST*
213   50   50
214   03   3
215   00   0
216   04   4
217   03   3
218   07   7
219   01   1
220   00   0
221   00   0
222   00   0
223   00   0
224   69 □P
225   02   02
226   69 □P
227   05   05
228   91 R/S
229   99 PRT
230   72 ST*
231   51   51
232   69 □P
233   00   00
234   04   4
235   04   4
236   07   7
237   01   1
238   69 □P
239   02   02
240   69 □P
241   05   05
242   91 R/S
243   99 PRT
244   72 ST*
245   52   52
246   97 DSZ
247   00   00
248   38 SIN
249   43 RCL
250   58   58
251   42 STO
252   00   00
253   42 STO
254   59   59
255   12   B
256   61 GTO
257   87 IFF
258   76 LBL
259   13   C
260   98 ADV
261   22 INV
262   58 FIX
263   04   4
264   02   2
265   02   2
266   04   4
267   03   3
268   06   6
269   69 □P
270   04   04
271   58 FIX
272   04   04
273   43 RCL
274   54   54
275   69 □P
276   06   06
277   91 R/S
```

Program Listing Viscosity Program (Cont'd)

APPENDIX E

USER INSTRUCTIONS AND PROGRAM LISTING FOR SPLINE FIT PROGRAM

GENERAL

The spline fit program fits a spline function between six data points, x and y_i i = 1 to 6. The function can be used to interpolate values of y between the data points. The spline function also can be used to estimate the derivative dy/dx anywhere in the interval x_i to x_N. The program uses the PC-100A printer.

Nomenclature, in order used by program:

X	=	x variable
Y	=	y variable
TOL	=	Tolerance for numerical solution (0.0001 is adequate)
T	=	Value of x for which interpolated values of y are desired
S"(T)	=	d^2y/dx at x = T
S(T)	=	Value of y at x = T
S'(T)	=	dy/dx at x = T

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Enter side 1 of Card 1		Clr	1	
	Enter side 2 of Card 1		Clr	2	
2	Clear memory and initialize		2nd Cms E	-1	
3	Enter data		A		X?
	X must be	x_1			x_1
	entered in order				Y?
	from smallest to	y_1			y_1
	largest				
					.
					.
					.

Step	Procedure	Enter	Press	Display	Print
		x_n			x_n
					Y?
		y_n			y_n
					TOL?
		TOL			TOL
4	Program calculates for about 2 minutes				INPUT T's
5	Enter T	T_1			T_1
		.			.
		.			.
		.			.
		T_N			T_N
6	Finish Card 1				READ Card 2
7	Read side 1 of card 2		Clr	1	
	Read side 2 of Card 1		Clr	2	
8	Calculate		A		T =
					T_1
					S"
					Numbers
					S(TXX1)
					Numbers
					S(T)
					Numbers
					S'(T)
					Numbers
					.
					.
					.
					.
					END
9	Save T_i and $S'(T_i)$ by recording on magnetic card for later use	3	2nd Write	3	

SPLINE FIT CARD 1

000	76	LBL
001	15	E
002	00	0
003	42	STO
004	27	27
005	42	STO
006	32	32
007	01	1
008	94	+/-
009	42	STO
010	49	49
011	76	LBL
012	10	E'
013	01	1
014	42	STO
015	50	50
016	07	7
017	42	STO
018	51	51
019	01	1
020	03	3
021	42	STO
022	52	52
023	01	1
024	08	8
025	42	STO
026	53	53
027	02	2
028	03	3
029	42	STO
030	54	54
031	02	2
032	08	8
033	42	STO
034	55	55
035	03	3
036	03	3
037	42	STO
038	56	56
039	43	RCL
040	49	49
041	42	STO
042	00	00
043	92	RTN
044	76	LBL
045	11	A
046	06	6
047	42	STO
048	00	00
049	76	LBL
050	60	DEG
051	69	DP
052	00	00
053	04	4
054	04	4
055	00	0
056	00	0
057	07	7
058	01	1
059	69	DP
060	02	02
061	69	DP
062	05	05
063	91	R/S
064	99	PRT
065	72	ST*
066	50	50
067	69	DP
068	00	00
069	04	4
070	05	5
071	00	0
072	00	0
073	07	7
074	01	1
075	69	DP
076	02	02
077	69	DP
078	05	05
079	91	R/S
080	99	PRT
081	72	ST*
082	51	51
083	01	1
084	44	SUM
085	50	50
086	44	SUM
087	51	51
088	44	SUM
089	49	49
090	97	DSZ
091	00	00
092	60	DEG
093	76	LBL
094	12	B
095	69	DP
096	00	00
097	03	3
098	07	7
099	03	3
100	02	2

```
101  02   2
102  07   7
103  07   7
104  01   1
105  69  □P
106  02   02
107  69  □P
108  05   05
109  91  R/S
110  99  PRT
111  42  STO
112  37   37
113  76  LBL
114  13   C
115  10  E'
116  76  LBL
117  38  SIN
118  43  RCL
119  50   50
120  85   +
121  01   1
122  95   =
123  42  STO
124  40   40
125  43  RCL
126  51   51
127  85   +
128  01   1
129  95   =
130  42  STO
131  41   41
132  73  RC*
133  40   40
134  75   -
135  73  RC*
136  50   50
137  95   =
138  72  ST*
139  52   52
140  35  1/X
141  65   ×
142  53   (
143  73  RC*
144  41   41
145  75   -
146  73  RC*
147  51   51
148  54   )
149  95   =
150  72  ST*
151  53   53
152  01   1
153  44  SUM
154  50   50
155  44  SUM
156  51   51
157  44  SUM
158  52   52
159  44  SUM
160  53   53
161  97  DSZ
162  00   00
163  38  SIN
164  76  LBL
165  14   D
166  10  E'
167  04   4
168  42  STO
169  00   00
170  76  LBL
171  39  COS
172  43  RCL
173  53   53
174  85   +
175  01   1
176  95   =
177  42  STO
178  40   40
179  43  RCL
180  52   52
181  85   +
182  01   1
183  95   =
184  42  STO
185  41   41
186  73  RC*
187  52   52
188  85   +
189  73  RC*
190  41   41
191  95   =
192  42  STO
193  38   38
194  35  1/X
195  65   ×
196  93   .
197  05   5
198  65   ×
199  73  RC*
200  52   52
201  95   =
```

Spline Fit Card 1 (Cont'd)

Reproduced from
best available copy.

202	72	ST*
203	54	54
204	02	2
205	65	×
206	53	(
207	73	RC*
208	40	40
209	75	-
210	73	RC*
211	53	53
212	54	)
213	55	÷
214	43	RCL
215	38	38
216	95	=
217	72	ST*
218	55	55
219	65	×
220	03	3
221	55	÷
222	02	2
223	95	=
224	72	ST*
225	56	56
226	01	1
227	44	SUM
228	53	53
229	44	SUM
230	52	52
231	44	SUM
232	54	54
233	44	SUM
234	55	55
235	44	SUM
236	56	56
237	97	DSZ
238	00	00
239	39	COS
240	76	LBL
241	16	A'
242	00	0
243	32	X:T
244	10	E'
245	04	4
246	42	STO
247	00	00
248	76	LBL
249	70	RAD
250	43	RCL
251	55	55
252	85	+
253	01	1
254	95	=
255	42	STO
256	40	40
257	75	-
258	02	2
259	95	=
260	42	STO
261	41	41
262	01	1
263	93	.
264	00	0
265	07	7
266	01	1
267	07	7
268	09	9
269	06	6
270	08	8
271	65	×
272	53	(
273	73	RC*
274	55	55
275	94	+/-
276	75	-
277	73	RC*
278	54	54
279	65	×
280	73	RC*
281	41	41
282	75	-
283	53	(
284	93	.
285	05	5
286	75	-
287	73	RC*
288	54	54
289	54	)
290	65	×
291	73	RC*
292	40	40
293	85	+
294	73	RC*
295	56	56
296	54	)
297	95	=
298	42	STO
299	44	44
300	50	I×I

```
301  22 INV
302  77  GE
303  87 IFF
304  32 X:T
305  76 LBL
306  87 IFF
307  43 RCL
308  44  44
309  74 SM*
310  55  55
311  01   1
312  44 SUM
313  55  55
314  44 SUM
315  54  54
316  44 SUM
317  56  56
318  97 DSZ
319  00  00
320  70 RAD
321  43 RCL
322  37  37
323  22 INV
324  77  GE
325  16 A'
326  76 LBL
327  17 B'
328  10 E'
329  03   3
330  03   3
331  42 STO
332  40  40
333  05   5
334  42 STO
335  00  00
336  76 LBL
337  80 GRD
338  43 RCL
339  55  55
340  75   -
341  01   1
342  95   =
343  42 STO
344  41  41
345  53   (
346  73 RC*
347  55  55
348  75   -
349  73 RC*
350  41  41
351  54   )
352  55   ÷
353  73 RC*
354  52  52
355  95   =
356  72 ST*
357  40  40
358  01   1
359  44 SUM
360  55  55
361  44 SUM
362  40  40
363  44 SUM
364  52  52
365  97 DSZ
366  00  00
367  80 GRD
368  03   3
369  09   9
370  42 STO
371  50  50
372  06   6
373  42 STO
374  00  00
375  76 LBL
376  18 C'
377  69 OP
378  00  00
379  02   2
380  04   4
381  03   3
382  01   1
383  03   3
384  03   3
385  04   4
386  01   1
387  03   3
388  07   7
389  69 OP
390  01  01
391  03   3
392  07   7
393  06   6
394  05   5
395  03   3
396  06   6
397  69 OP
398  02  02
399  69 OP
400  05  05
401  91 R/S
```

Spline Fit Card 1 (Cont'd)

```
402  72 ST*
403  50  50
404  99 PRT
405  01   1
406  44 SUM
407  50  50
408  97 DSZ
409  00  00
410  18 C'
411  69 DP
412  00  00
413  03   3
414  05   5
415  01   1
416  07   7
417  01   1
418  03   3
419  01   1
420  06   6
421  00   0
422  00   0
423  69 DP
424  01  01
425  01   1
426  05   5
427  01   1
428  03   3
429  03   3
430  05   5
431  01   1
432  06   6
433  00   0
434  00   0
435  69 DP
436  02  02
437  00   0
438  03   3
439  00   0
440  00   0
441  00   0
442  00   0
443  00   0
444  00   0
445  00   0
446  00   0
447  69 DP
448  03  03
449  69 DP
450  05  05
451  01   1
452  91 R/S
```

Spline Fit Card 1 (Cont'd)

```
SPLINE FIT CARD 2
      000  76 LBL
      001  11  A
      002  04  4
      003  04  4
      004  42 STO
      005  58  58
      006  03  3
      007  09  9
      008  42 STO
      009  56  56
      010  06  6
      011  42 STO
      012  00  00
      013  01  1
      014  42 STO
      015  51  51
      016  00  0
      017  32 X:T
      018  76 LBL
      019  87 IFF
      020  43 RCL
      021  00  00
      022  73 RC*
      023  56  56
      024  42 STO
      025  59  59
      026  43 RCL
      027  59  59
      028  75  -
      029  43 RCL
      030  01  01
      031  95  =
      032  67  EQ
      033  79  x̄
      034  22 INV
      035  77  GE
      036  88 DMS
      037  43 RCL
      038  59  59
      039  75  -
      040  43 RCL
      041  06  06
      042  95  =
      043  67  EQ
      044  78 Σ+
      045  77  GE
      046  88 DMS
      047  43 RCL
      048  59  59
      049  75  -
      050  73 RC*
      051  51  51
      052  95  =
      053  67  EQ
      054  79  x̄
      055  22 INV
      056  77  GE
      057  67  EQ
      058  01  1
      059  44 SUM
      060  51  51
      061  97 DSZ
      062  00  00
      063  87 IFF
      064  76 LBL
      065  88 DMS
      066  69 DP
      067  00  00
      068  01  1
      069  07  7
      070  03  3
      071  05  5
      072  03  3
      073  05  5
      074  03  3
      075  02  2
      076  03  3
      077  05  5
      078  69 DP
      079  02  02
      080  69 DP
      081  05  05
      082  61 GTO
      083  69 DP
      084  76 LBL
      085  78 Σ+
      086  06  6
      087  42 STO
      088  51  51
      089  76 LBL
      090  67  EQ
      091  01  1
      092  22 INV
      093  44 SUM
      094  51  51
      095  76 LBL
      096  79  x̄
      097  12  B
      098  76 LBL
      099  69 DP
      100  01  1
```

Spline Fit Card 2

```
101  44 SUM
102  56  56
103  01   1
104  42 STO
105  51  51
106  06   6
107  42 STO
108  00  00
109  43 RCL
110  56  56
111  75   -
112  04   4
113  05   5
114  95   =
115  22 INV
116  67  EQ
117  87 IFF
118  69 DP
119  00  00
120  01   1
121  07   7
122  03   3
123  01   1
124  01   1
125  06   6
126  69 DP
127  02  02
128  69 DP
129  05  05
130  92 RTN
131  76 LBL
132  12   B
133  01   1
134  44 SUM
135  58  58
136  43 RCL
137  51  51
138  85   +
139  06   6
140  95   =
141  42 STO
142  52  52
143  85   +
144  01   1
145  01   1
146  95   =
147  42 STO
148  53  53
149  85   +
150  09   9
151  95   =
152  42 STO
153  54  54
154  85   +
155  06   6
156  95   =
157  42 STO
158  55  55
159  43 RCL
160  59  59
161  75   -
162  73 RC*
163  51  51
164  95   =
165  42 STO
166  23  23
167  01   1
168  44 SUM
169  51  51
170  43 RCL
171  59  59
172  75   -
173  73 RC*
174  51  51
175  95   =
176  42 STO
177  24  24
178  65   ×
179  43 RCL
180  23  23
181  95   =
182  42 STO
183  25  25
184  98 ADV
185  69 DP
186  00  00
187  03   3
188  07   7
189  00   0
190  00   0
191  06   6
192  04   4
193  69 DP
194  02  02
195  69 DP
196  05  05
197  43 RCL
198  59  59
199  99 PRT
200  69 DP
```

Spline Fit Card 2 (Cont'd)

201	00	00
202	03	3
203	06	6
204	06	6
205	05	5
206	06	6
207	05	5
208	69	□P
209	02	02
210	69	□P
211	05	05
212	73	RC*
213	54	54
214	42	STO
215	51	51
216	85	+
217	43	RCL
218	23	23
219	65	×
220	73	RC*
221	55	55
222	95	=
223	99	PRT
224	42	STO
225	26	26
226	69	□P
227	00	00
228	03	3
229	06	6
230	05	5
231	05	5
232	03	3
233	07	7
234	04	4
235	04	4
236	04	4
237	04	4
238	69	□P
239	02	02
240	00	0
241	02	2
242	05	5
243	06	6
244	00	0
245	00	0
246	00	0
247	00	0
248	00	0
249	00	0
250	69	□P
251	03	03
252	69	□P
253	05	05
254	01	1
255	44	SUM
256	54	54
257	53	(
258	73	RC*
259	54	54
260	85	+
261	43	RCL
262	51	51
263	85	+
264	43	RCL
265	26	26
266	54	)
267	55	÷
268	06	6
269	95	=
270	99	PRT
271	42	STO
272	57	57
273	69	□P
274	00	00
275	03	3
276	06	6
277	05	5
278	05	5
279	03	3
280	07	7
281	05	5
282	06	6
283	69	□P
284	02	02
285	69	□P
286	05	05
287	73	RC*
288	52	52
289	85	+
290	43	RCL
291	23	23
292	65	×
293	73	RC*
294	53	53
295	85	+
296	53	(
297	43	RCL
298	25	25
299	65	×
300	43	RCL

Spline Fit Card 2 (Cont'd)

```
301  57  57
302  54  )
303  95  =
304  99 PRT
305  69 DP
306  00  00
307  03  3
308  06  6
309  06  6
310  05  5
311  05  5
312  05  5
313  03  3
314  07  7
315  05  5
316  06  6
317  69 DP
318  02  02
319  69 DP
320  05  05
321  73 RC*
322  53  53
323  85  +
324  53  (
325  43 RCL
326  23  23
327  85  +
328  43 RCL
329  24  24
330  54  )
331  65  ×
332  43 RCL
333  57  57
334  85  +
335  53  (
336  43 RCL
337  25  25
338  65  ×
339  73 RC*
340  55  55
341  55  ÷
342  06  6
343  54  )
344  95  =
345  99 PRT
346  72 ST*
347  58  58
348  98 ADV
349  92 RTN
```

Spline Fit Card 2 (Cont'd)

APPENDIX F

USER INSTRUCTIONS AND PROGRAM LISTING FOR CALCULATION OF PENETRATION AS A FUNCTION OF PARTICLE DIAMETER PROGRAM FOR TI-59

GENERAL

This program is used in conjunction with the spline fit program to calculate penetration as a function of particle diameter. Magnetic cards are used to input the results from the spline fit program needed in this program. Particle diameter, penetration for that diameter, and overall penetration are printed on the PC-100A printer.

Nomenclature, in order used by program:

Mass In	= Particulate mass concentration at inlet
Mass Out	= Particulate mass concentration at outlet
D	= Particle diameter, μm
PT(D)	= Penetration for particle diameter, d, fraction
Overall PT	= Overall penetration, $\frac{\text{Mass (out)}}{\text{Mass (in)}}$

USER INSTRUCTIONS

Step	Procedure	Enter	Press	Display	Print
1	Read side 1 of card		Clr	1	
	Read side 2 of card		Clr	2	
2	Begin calculation		A	3	READ INLET DATA
	Read magnetic card with		Clr		
	results from spline fit		R/S		
	for inlet				
				3	READ OUTLET DATA
	Read magnetic card with results		Clr		
	from spline fit for outlet		R/S		
					MASS IN?
	Enter inlet mass concentration, M_I		R/S		MASS OUT?
	Enter outlet mass concentration, M_O		R/S		D = number

Step	Procedure	Enter	Press	Display	Print
					PT(D) =
					.
					.
					.
					D =
					number
					PT(D) =
					number
					Overall PT
					number
					END

```
000  76 LBL
001  12  B
002  69 OP
003  00  00
004  03  3
005  00  0
006  01  1
007  03  3
008  03  3
009  06  6
010  03  3
011  06  6
012  00  0
013  00  0
014  69 OP
015  01  01
016  02  2
017  04  4
018  03  3
019  01  1
020  07  7
021  01  1
022  00  0
023  00  0
024  00  0
025  00  0
026  69 OP
027  02  02
028  69 OP
029  05  05
030  91 R/S
031  99 PRT
032  42 STO
033  25  25
034  03  3
035  02  2
036  04  4
037  01  1
038  03  3
039  07  7
040  07  7
041  01  1
042  00  0
043  00  0
044  69 OP
045  02  02
046  69 OP
047  05  05
048  91 R/S
049  99 PRT
050  42 STO
051  26  26
052  92 RTN
053  76 LBL
054  11  A
055  69 OP
056  00  00
057  03  3
058  05  5
059  01  1
060  07  7
061  01  1
062  03  3
063  01  1
064  06  6
065  00  0
066  00  0
067  69 OP
068  01  01
069  02  2
070  04  4
071  03  3
072  01  1
073  02  2
074  07  7
075  01  1
076  07  7
077  03  3
078  07  7
079  69 OP
080  02  02
081  00  0
082  00  0
083  01  1
084  06  6
085  01  1
086  03  3
087  03  3
088  07  7
089  01  1
090  03  3
091  69 OP
092  03  03
093  69 OP
094  05  05
095  03  3
096  91 R/S
097  03  3
098  09  9
099  42 STO
100  20  20
101  01  1
102  42 STO
103  21  21
104  04  4
105  05  5
106  42 STO
107  22  22
108  07  7
109  42 STO
110  23  23
111  06  6
112  42 STO
113  00  00
114  76 LBL
115  60 DEG
116  73 RC*
117  20  20
118  72 ST*
119  21  21
120  73 RC*
121  22  22
122  72 ST*
123  23  23
124  01  1
125  44 SUM
126  20  20
127  44 SUM
128  21  21
129  44 SUM
130  22  22
131  44 SUM
132  23  23
133  97 DSZ
134  00  00
135  60 DEG
136  03  3
137  02  2
138  04  4
139  01  1
140  03  3
141  07  7
142  02  2
143  07  7
144  01  1
145  07  7
146  69 OP
147  02  02
148  03  3
149  07  7
150  00  0
```

```
151  00   0
152  01   1
153  06   6
154  01   1
155  03   3
156  03   3
157  07   7
158  69 DP
159  03   03
160  01   1
161  03   3
162  00   0
163  00   0
164  00   0
165  00   0
166  00   0
167  00   0
168  00   0
169  00   0
170  69 DP
171  04   04
172  69 DP
173  05   05
174  03   3
175  91 R/S
176  04   4
177  05   5
178  42 STO
179  22   22
180  01   1
181  03   3
182  42 STO
183  23   23
184  06   6
185  42 STO
186  00   00
187  76 LBL
188  70 RAD
189  73 RC*
190  22   22
191  72 ST*
192  23   23
193  01   1
194  44 SUM
195  22   22
196  44 SUM
197  23   23
198  97 DSZ
199  00   00
200  70 RAD
```

```
201  12   B
202  43 RCL
203  26   26
204  55   ÷
205  43 RCL
206  25   25
207  95   =
208  42 STO
209  27   27
210  01   1
211  42 STO
212  20   20
213  07   7
214  42 STO
215  21   21
216  01   1
217  03   3
218  42 STO
219  22   22
220  06   6
221  42 STO
222  00   00
223  76 LBL
224  80 GRD
225  73 RC*
226  22   22
227  55   ÷
228  73 RC*
229  21   21
230  65   ×
231  43 RCL
232  27   27
233  95   =
234  42 STO
235  30   30
236  69 DP
237  00   00
238  01   1
239  06   6
240  00   0
241  00   0
242  06   6
243  04   4
244  69 DP
245  02   02
246  69 DP
247  05   05
248  73 RC*
249  20   20
250  99 PRT
```

```
251  69 DP
252  00   00
253  03   3
254  03   3
255  03   3
256  07   7
257  05   5
258  05   5
259  01   1
260  06   6
261  05   5
262  06   6
263  69 DP
264  01   01
265  00   0
266  00   0
267  06   6
268  04   4
269  00   0
270  00   0
271  00   0
272  00   0
273  00   0
274  00   0
275  69 DP
276  02   02
277  69 DP
278  05   05
279  43 RCL
280  30   30
281  99 PRT
282  01   1
283  44 SUM
284  20   20
285  44 SUM
286  21   21
287  44 SUM
288  22   22
289  97 DSZ
290  00   00
291  80 GRD
292  69 DP
293  00   00
294  03   3
295  02   2
296  04   4
297  02   2
298  01   1
299  07   7
300  03   3
```

Program Listing Pt(d) Program for TI-59 (Cont'd)

```
301  05  5
302  01  1
303  03  3
304  69  OP
305  01   01
306  02  2
307  07  7
308  02  2
309  07  7
310  00  0
311  00  0
312  03  3
313  03  3
314  03  3
315  07  7
316  69  OP
317  02   02
318  00  0
319  00  0
320  06  6
321  04  4
322  00  0
323  00  0
324  00  0
325  00  0
326  00  0
327  00  0
328  69  OP
329  03   03
330  69  OP
331  05   05
332  43  RCL
333  27   27
334  99  PRT
335  69  OP
336  00   00
337  01  1
338  07  7
339  03  3
340  01  1
341  01  1
342  06  6
343  00  0
344  00  0
345  69  OP
346  02   02
347  69  OP
348  05   05
349  92  RTN
```